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Construction Vibration Impacts on the Center for Integrated Nanotechnologies

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Construction Vibration Impact on the Center for Integrated Nanotechnologies

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Abstract

Under the direction of the James W. Todd, Assistant Manager for Engineering within the National Nuclear Security Administration Sandia Field Office, the team listed above has performed the attached study to evaluate the vibration sensitivity of the Center for Integrated Nanotechnologies and propose possible mitigation strategies.

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EXECUTIVE SUMMARY

This SAND report was developed by representatives of National Technology and Engineering Solutions of Sandia (NTESS) at the request of the National Nuclear Security Administration – Sandia Field Office (NNSA-SFO), included in Appendix I. This request was prompted by the anticipated construction of the NNSA Albuquerque Complex Project (NACP) in the lot adjacent to the southern edge of Center for Integrated Nanotechnologies (CINT) Core Facility, building 518, starting in the fall of 2018. This report documents the background, sensitivities, and potential mitigation strategies to reduce the impact of vibrations on CINT during the construction of the NACP.

There have been three studies of the vibration environment of the CINT facility since 2002. The first study in 2002 was performed in order to verify that the vibration environment was suitable for locating a highly sensitive nano-science facility. This study demonstrated that siting CINT west of Eubank Boulevard in the Sandia Technology Park adequately reduced road vibrations and provided an acceptable level of aircraft noise to meet the vibration standard of VC-E (3 microns/second).

The second study, conducted under the direction of NNSA-SFO, was a simulation of the construction process that is believed to induce maximum vibrations, trenching and soil compaction. This study, performed in December 2016, found that vibrations observed at the North edge of the CINT facility induced from soil compaction exceeded VC-E by nearly a factor of 100. However, due to limitations in the resolution of the vibration sensors used in the study no further conclusions could be drawn.

The third study was performed in September of 2017 and forms the basis of this report. This study simulated construction traffic around the CINT facility using a newly installed vibration monitoring system within CINT. This system with resolution better than VC-E resolution provides 24-hours-a-day/7-day-a-week monitoring of the vibrations in the four labs located in the corners of the CINT facility. It will also allow monitoring during future construction projects in and around the CINT facility. This study concluded that the CINT facility is typically well below VC-E and the impact to CINT from construction traffic and actives south of the facility will typically also be below VC-E.

To reduce the potential impact of vibrations on the Atomic Precision Fabrication (APF) system, located closest to the southern edge of CINT, a piezoelectric driven active isolation system was purchased. This system will be installed in January 2018 and will provide additional robustness of the APF to anticipated construction vibrations.

This report concludes that CINT's AFP and transmission electron microscopy (TEM) capabilities will both be inoperable during the compaction process associated with NACP's construction. It is unclear what the impact of trenching will be, but it is believed that other construction activates will have minimal impact on CINT. Appropriate administrative controls and communication protocols must be established to allow both the construction of the NACP and continued operation of CINT. No long term impact is anticipated provided NACP uses appropriate mitigations in their facilities design. Detailed conclusions and recommendations from this committee are presented in section 7 of this document.

NOMENCLATURE

Abbreviation	Definition
APF	Atomic Precision Fabrication
BES	Basic Energy Sciences
CINT	Center for Integrated Nanotechnologies
NACP	NNSA Albuquerque Complex Project
NNSA	National Nuclear Security Administration
NSRC	Nanoscale Science Research Center
NTESS	National Technology and Engineering Solutions of Sandia
SFO	Sandia Field Office
SNL	Sandia National Laboratories
STEM	Scanning Transmission Electron Microscope
TEM	Transmission Electron Microscope
VC-E	Vibration Criterion level E (3.0 microns/second)

1. BACKGROUND

1.1. CINT Facility

The Center for Integrated Nanotechnologies (CINT) plays a leadership role in the integration of nanostructured materials to enable novel capabilities and applications through its function as a Department of Energy/Office of Science Nanoscale Science Research Center (NSRC) national user facility. By coupling open access to unique and world-class capabilities and scientific expertise to an active user community, CINT supports high-impact research that no other single institution could achieve.

CINT's vision is one scientific community focused on nanoscience integration.

Deriving the ultimate benefit from nanoscience will require the assembly of diverse nanoscale materials across multiple length scales to design and achieve new properties and functionality; in other words, nanomaterials integration. Integration has played a pivotal and revolutionary role in the development of nearly all science and technology. The most familiar and dramatic illustration is the development of very large-scale integrated circuits where active and passive devices based on semiconductors, dielectrics, insulators, and metals are monolithically integrated on a single platform for specific applications. Even greater challenges exist as nanomaterials are integrated into new architectures to form functional systems. Interfaces and defects are formed whose structures and properties can dominate the chemical, mechanical, electronic, and optical properties of the system. The effects of synthesis and fabrication processes on performance must be investigated and new directed- and self- assembly approaches developed for greater functional control. Combined bottom-up and top-down synthesis and assembly techniques must be optimized and/or invented to allow the intentional design of hierarchical materials. Establishing the fundamental principles that underpin the integration of nanomaterials that display unique properties, such as quantum confinement, is of paramount importance to nanoscience and ultimately nanotechnology.

CINT has two primary locations, one at Los Alamos National Laboratory, and the other (the CINT Core Facility shown in Figure 1.1.1.) located at Sandia National Laboratories in the Science and Technology Park.

Figure 1.1.1. The Center for Integrated Nanotechnologies Core Facility (Building 518)

On average, the CINT facilities host over 500 users per year from over 28 countries. Some of the nanointegration experiments are highly vibration sensitive and care must be taken to prevent long term disruptions in CINT's ability to meet its mission. Two tools have been identified as being the most highly vibration sensitive, the Atomic Precision Fabrication (APF) tool and the two CINT Transmission Electron Microscopes (TEMs). Both of these tools require the maximum vibration in the facility to stay below the VC-E (3.0 micron/seconds) design specification. These systems are described in detail in section 1.4. Figure 1.1.2. shows the floorplan of the CINT-Core facility with the locations of the TEM labs and APF tools called out.

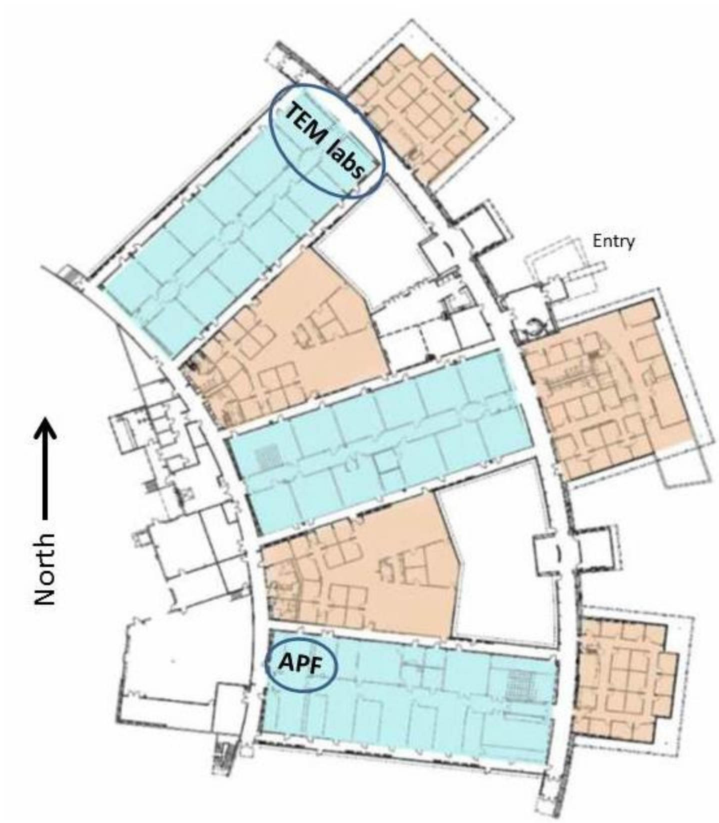
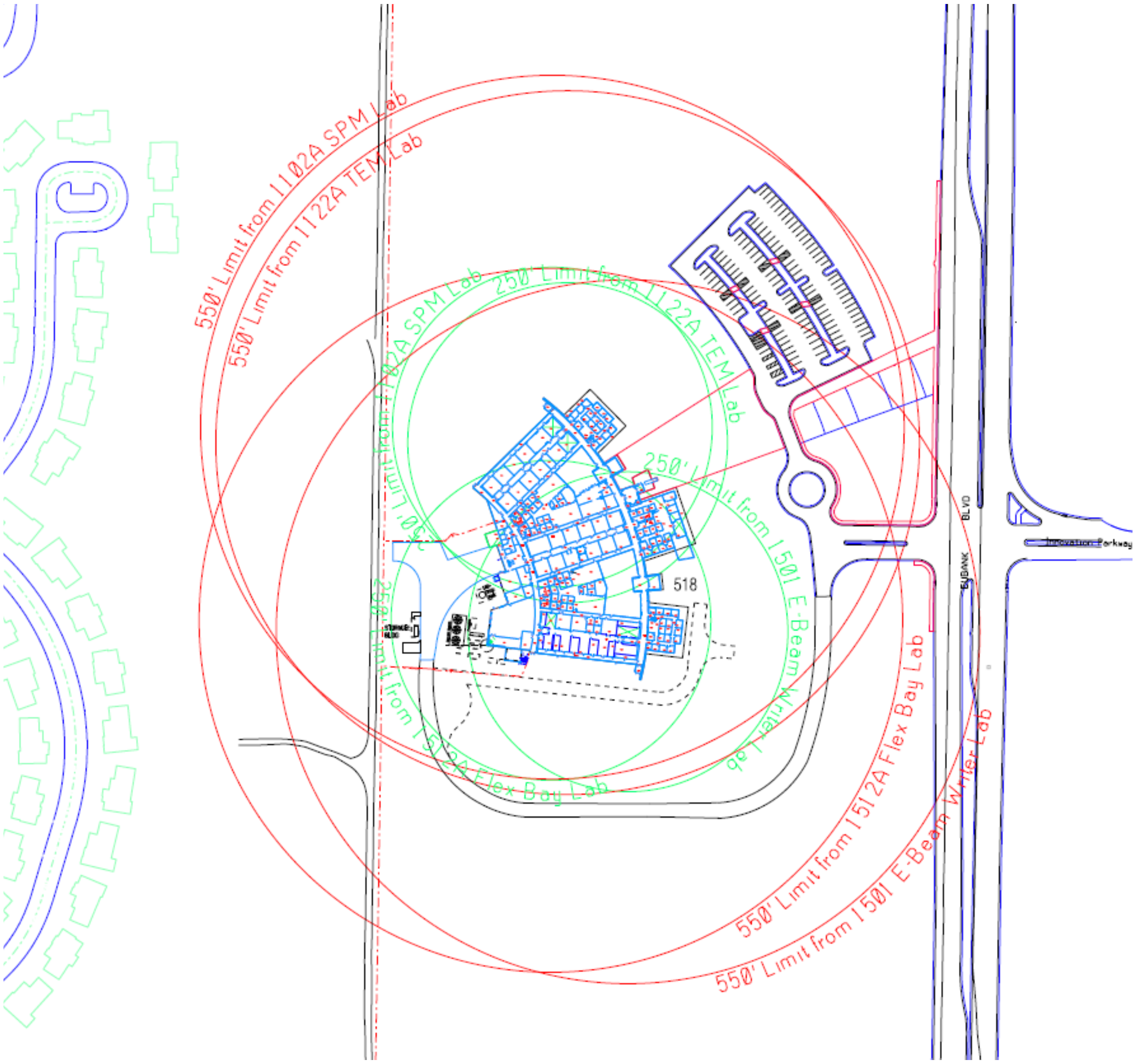


Figure 1.1.2. CINT Floorplan

Extensive studies of the intrinsic vibration of the plot on which CINT was eventually constructed were performed in 2002 by Colin Gordon & Associates (included in Appendix II). The key finding from the report was that the vibrations induced by light vehicle traffic was damped to VC-E (3 microns/sec), at approximately 250 feet from Eubank Boulevard and heavy vehicle vibrations met VC-E by 550 feet. "Building effects" were anticipated to reduce the vibrations that impacted tools within CINT, hence a proposed setback of 400 feet was deemed reasonable.



The CINT facility was sited so that the three key highly vibration sensitive laboratories, 1512, 1122, and 1102, would meet the 550 foot setback from Eubank Boulevard. Note, that there are laboratories with less than 550 foot setback, e.g., room 1501 e-Beam lab.

Figure 1.1.3. CINT Siting

Figure 1.1.3. is a schematic of the as-built location of the CINT-Core facility. The three laboratories that are the most sensitive to vibration, 1512, 1122, and 1102, are positioned to meet the 550 foot setback limit from Eubank Boulevard.

Prior to the construction of CINT in 2004, an agreement was reached between NNSA and BES as to a number of conditions including the maximum allowable vibration at CINT during construction or operation on the adjacent properties. This agreement (attached as Appendix III) includes a discussion of the need to minimize vibrations at the CINT facility due to the sensitive nature of the instruments. The remainder of this SAND report explores a set of experiments conducted by NNSA and by SNL in order to better understand the inherent vibration levels in the

CINT facility and the potential impacts of construction and operation of the NNSA Albuquerque Complex Project, which is planned to be located in the parcel immediately south of the CINT-Core facility.

1.2. NACP Facility

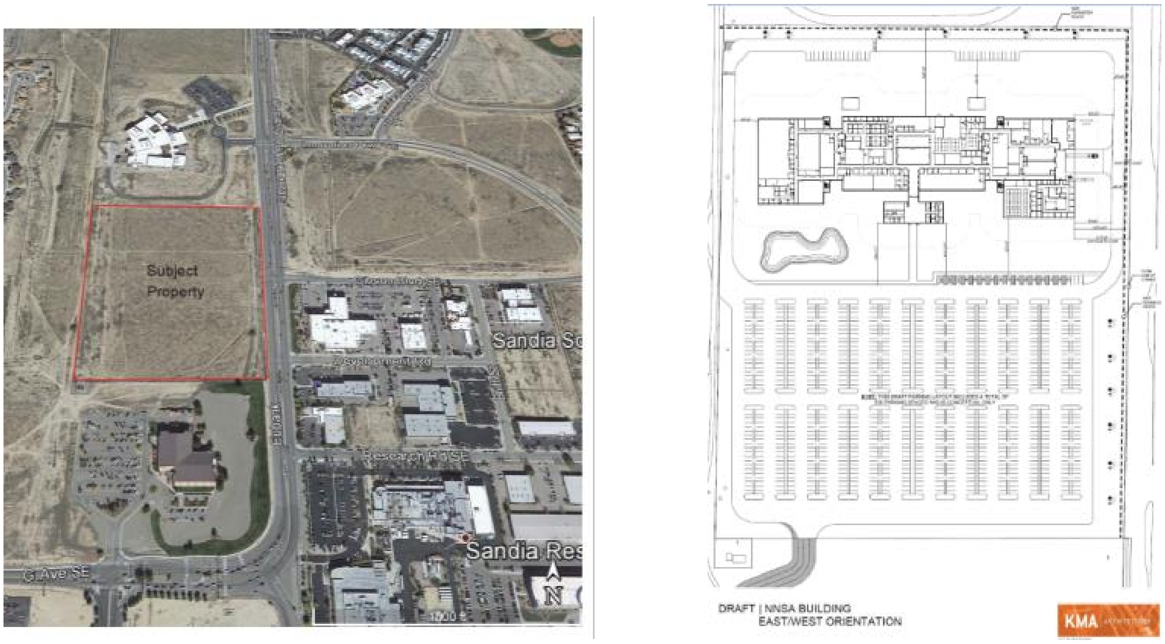
The NNSA Albuquerque Complex Project is a new facility to be built on the parcel immediately south of the CINT Core facility (Figure 1.2.1). This facility is slated for construction starting Fall 2018 and is anticipated to house around 1200 employees in its approximately 300,000 square feet of space.

Figure 1.2.1. NACP Facility Artist Rendition

This project is motivated by a number of factors. Foremost of which is that the infrastructure at the current Albuquerque Complex is problematic and office work space is less than desirable. Replacement of the current Albuquerque Complex began in the 1970s, with the Eubank Tract being transferred from the Air Force to DOE for construction of a new complex on November 19, 1979.

In 2015, just prior to release of the Request for Lease Proposals by the GSA, an Analysis of Alternatives was requested by the Management Council. The Analysis of Alternatives results showed that line-item construction was the best alternative.

The NEPA analysis for NACP included alternatives such as the new buildings on *either* the southern and northern portions of the Eubank Tract as well as building at the current site of the Albuquerque Complex. It was determined that the best location for the complex would be on the plot of land just south of the CINT facility (Figure 1.2.2.)



Aerial image of the proposed NACP facility location (left figure), anticipated layout of the facility (right figure)

Figure 1.2.2. NACP Facility Proposed Location

1.3. Directive from NNSA to NTESS

The May 9th, 2017 memo (Appendix I) from James W. Todd, Assistant Manager for Engineering, directed Susan J. Seestrom, Associate Laboratory Director Advanced Science and Technology, to implement the following:

> The SFO requests National Technology and Engineering Solutions of Sandia, LLC (NTESS) form an advisory panel, comprised of subject matter experts, to look at potential impacts to CINT, and identify mitigation strategies for NNSA to consider with regard to the construction and operations of the NACP. The SFO requests that NTESS invite a representative from BES to serve on this advisory panel. The SFO also requests NTESS to look at all mitigation strategies, to include engineering, and administrative controls that can be implemented with respect to the site, facility (CINT), and operations (work scheduling and planning). Please consider strategies associated with the construction and operations of the NACP, as well as any future development (i.e., Kirtland Air Force Base, NNSA, City of Albuquerque) that may occur in the area that could potentially impact CINT operations. By November 1, 2017, please provide the SFO with recommended mitigation strategies associated with the construction and operations of the NACP, the operations at the CINT, and future development in the area.

In response to this directive, Sean J. Hearne, Sr. Manager 1880, was tasked with organizing a committee to perform the analysis presented in this SAND report. This document is the committee's best effort to respond to the directive.

The committee was made up of the following individuals:

Sean J. Hearne (chair) – Sandia National Labs Senior Manager with primary oversight of the CINT Core Facility (building 518)

Ted Kostranchuk – Sandia National Laboratories Facilities Engineering Project Manager with oversight of the vibration testing system and on-site vibration experiments

Katherine Jungjohann – Principal Member of Technical Staff and owner of CINT's two transmission electron microscopes

Ezra Bussmann - Principal Member of Technical Staff and owner of CINT's two Atomic Precision Fabrication systems

Brian Swartzentruber – Manager of Organization 1882 and subject matter expert in atomic surface probes

Karl Weiss (Arizona State University) - John M. Cowley Center for High Resolution Electron Microscopy Manager

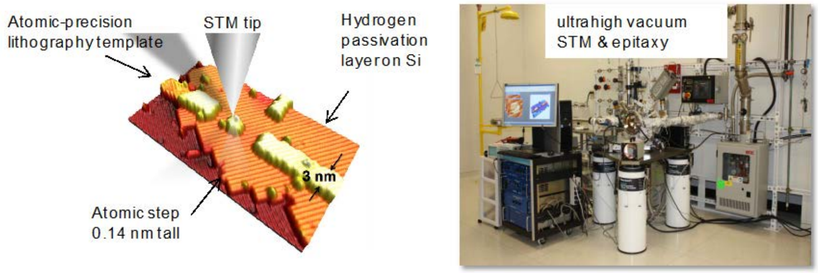
Victor Wowk (Machine Dynamics, Inc.) – Senior Vibration Analyst and Professional Engineer (P.E.)

The Office of Science BES respectfully declined the invitation to have representation on the committee.

1.4. Descriptions of CINT Vibration Sensitive Capabilities

1.4.1. Atomic Precision Fabrication

This tool is used to fabricate and image atomic-sized structures on material surfaces. The system creates atomic-precision lithography templates by opening holes in a single atomic layer thick hydrogen mask (see Figure 1.4.1 below). The templates have atomically sharp precision with feature sizes from a single atom up to 10 micrometers. The templates are formed using a scanning tunneling microscope (STM) probe as depicted in Figure 1.4.1 below. Then, selective chemical vapor deposition (CVD) via the lithographic template is used to dope Si via the template. Applications for the tool include quantum device fabrication, tailored atomically-registered surface functionalization for chemistry and materials growth studies, donor-array based tunable electronic materials, and thin-film growth studies via molecular beam epitaxy. This is one of three such systems in the United States and the only one within the DOE labs.



A schematic representation of an atomic surface being modified by the STM tip (left figure), one of the APF tools that is located in CINT (right figure).

Figure 1.4.1. CINT's Atomic Precision Fabrication Capability

Table 1.4.1. APF Vibration Sensitivity

Frequency range	Floor vibration level
1 – 2 Hz	1.6 μm/s $_{pp}$
2 – 10 Hz	4 μm/s $_{pp}$
10 – 20 Hz	32 μm/s $_{pp}$
20 – 50 Hz	50 μm/s $_{pp}$
50 – 100 Hz	10 μm/s $_{pp}$
> 100 Hz	10 μm/s $_{pp}$

1.4.2. Transmission Electron Microscopes

A TEM is a microscope that uses electrons focused with magnetic lenses to resolve structures down to the atomic scale in materials. Due to the fine detail being resolved in the materials, these microscopes require a specialized environment for optimal performance. Site surveys are conducted within a building prior to the installation of the system to ensure the magnetic fields are below 30 nT, thermal fluctuations are below 0.1°C/30 min, and floor vibrations are below VC-E to VC-F levels. Disturbances from these specifications can degrade the atomic-scale information in the images or can cause large thermal drift which will blur the images.

The FEI Tecnai G2 F30 TEM, located in lab 1102 of the CINT building, operates with 100-300 keV electrons for imaging in parallel beam (TEM) or scanning probe (STEM) modes of imaging. In TEM mode, images are collected on a CCD after transmission of the incident electrons through the specimen, where elastic scattering from the material creates contrast as a shadow image from the material. The electrons that lose energy by interacting with the specimen, inelastically scattered, can be collected using spectrometers for electrons and x-rays. These spectrometers provide compositional information from the sample. The great value in TEM, in comparison to bulk characterization techniques, is the site specific nature of the information. Data can be collected of the structure and composition at a grain boundary in a metal, for instance, which no other technique can achieve. Sensitivity to single atoms is the advantage of STEM imaging, where the resolution of the image depends on the size of the electron probe. Therefore, disturbances in the formation or raster of this probe will degrade the ability to obtain single atom sensitivity with these instruments. The resolution of the Tecnai in TEM mode is 0.14 nm, where in STEM mode it is capable of 0.164 nm. The value of the Tecnai F30 with added spectrometers is about $2.5 million US.

(00 kV FEI Tecnai G2 F30 TEM (left image), 300 kV FEI Titan ETEM (right image).

Figure 1.4.2. CINT's TEMs

The FEI Titan Environmental TEM (ETEM), located in lab 1122 of the CINT building, operates with 200-300 keV electrons where additional lenses have been added to this TEM to allow for decreased energy spread of the electrons emitted from the source (monochromator), and corrected beam pathways for electrons traveling off the center axis in the column (image-corrected, C_s-corrected). These additional lenses increase the sensitivity of the instrument for optimal performance. The resolution of the Titan—image-corrected in TEM mode—is 0.09 nm, where in STEM mode it is capable of 0.136 nm. The value of the Titan ETEM with added monochromater, stabilized electron emitter, image-corrector, cameras, and piezo-stage is about $7.8 million US.

The differences in the imaging abilities between the Tecnai and the Titan, is represented by the vibration requirements for optimal imaging. The Tecnai can be operated to specification with VC-E (3.12 μm/s) vertical vibrations, Figure 1.4.2, whereas the Titan requires VC-F (1.56 μm/s), Figure 1.4.3 As STEM imaging is more susceptible to image distortions by vertical vibrations, the vibration test with the dump truck was completed during STEM imaging on the Titan ETEM.

3.6.1 VC Curves

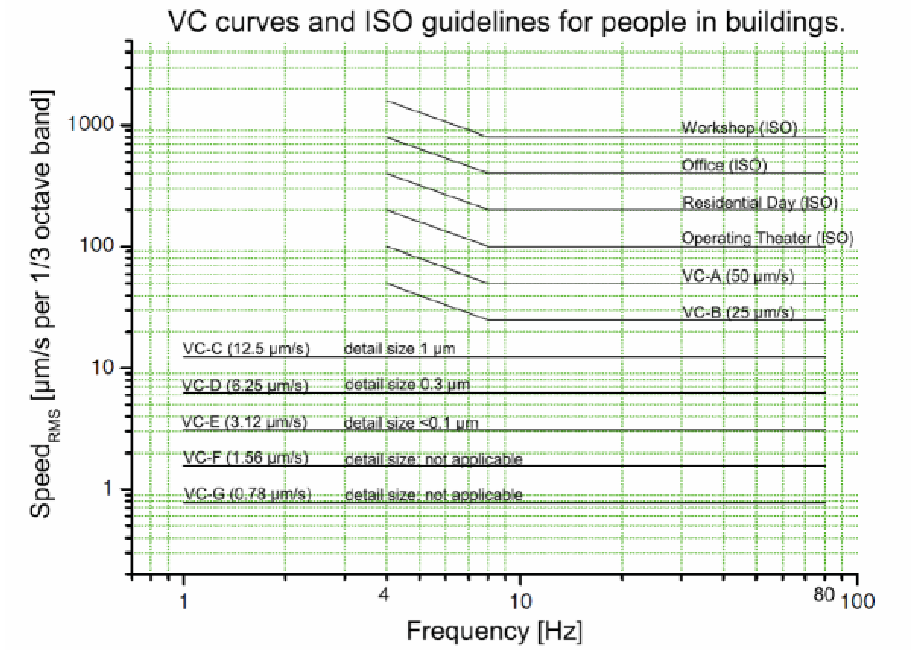


Fig. 3-4: VC Curves

For Tecnai G2 30, guidelines provided by the VC-curves can be interpreted as described below. In each table there are listed applicable VC-curves for certain direction and system.

System	Vertical	Left to right	Front to back
Tecnai G2 TF30 Twin (Polara); TEM info limit 0.16nm	E	F	F
Tecnai G2 TF30 Twin (Polara); STEM res. 0.344nm	E	F	F
Tecnai G2 T20-T30 Twin (Sphera) ST-UT; TEM line res. 0.144nm	E	F	F
Tecnai G2 TF30 ST; TEM info limit 0.14nm	E	F	F
Tecnai G2 TF30 ST; STEM res. 0.164nm	E	F	F
Tecnai G2 TF30 UT; TEM info limit 0.12nm	F	G	G
Tecnai G2 TF30 UT; STEM res. 0.144nm	F	G	G

Table 1: VC-curves

Manufacturer's vibration requirements for the Tecnai F30, super-twin objective lens.

Figure 1.4.3. Tecnai F30 Requires VC-E (vertically) for Optimal Imaging

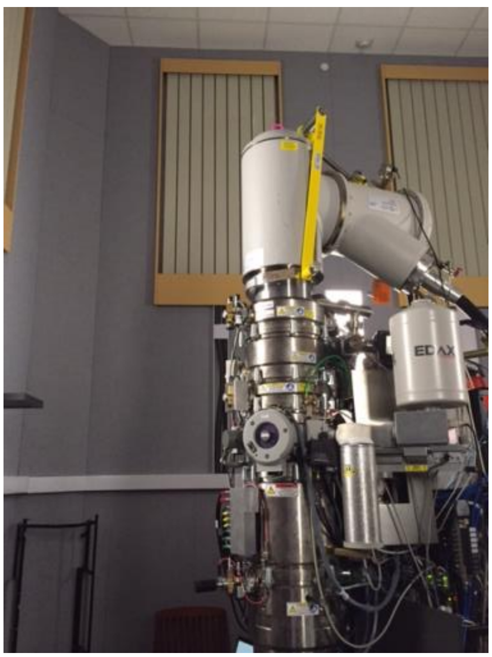
Table 1.4.2. Titan ETEM Requires VC-F (vertically) for Optimal Imaging

System	Vertical	Left to right	Front to back
Titan E-TEM (Non-corrected); TEM info limit 0.10nm	E	F	F
Titan E-TEM (Non-corrected); STEM res. 0.136nm	E	F	F
Titan E-TEM; CsImage; TEM info limit 0.10nm	E	F	F
Titan E-TEM; CsImage; STEM res. 0.136nm	E	F	F
Titan E-TEM; Mono; TEM info limit 0.10nm	E	F	F
Titan E-TEM; Mono; STEM res. 0.136nm	E	F	F
Titan E-TEM; CsImage+Mono; TEM info limit 0.09nm	F	G	G
Titan E-TEM; CsImage+Mono; STEM res. 0.136nm	F	G	G

2. ARIZONA STATE UNIVERSITY MICROSCOPY FACILITY

To collect background information on state-of-the-art vibration control for a facility, a sub-set of the team performed a site visit to Arizona State University's (ASU's) John M. Cowley Center for High Resolution Electron Microscopy. The facility, managed by Prof. Karl Weiss, houses eight transmission electron microscopes, including a FEI Titan 300 that is similar to the ETEM that CINT has recently installed.

This facility was built specifically for use as an electron microscopy facility and extreme measures were taken to ensure the most stable environment possible for the microscopes. The challenges of locating the microscopy facility at the ASU Tempe campus include: the site being adjacent to major campus traffic, overhead aircraft from Sky Harbor's departure path, and temperature fluctuations from 80F to 120F in the summer.



(Left) Techni F20 TEM system. (Right) Wall mounted thermal radiator system.

Figure 2.1. Representative ASU TEM room

To mitigate the environmental noise, a 42 inch thick reinforced concrete slab was poured, which weighs approximately 2 million pounds. The walls are 12 inches thick and in the microscopy rooms, there is an additional layer of concrete blocks to mitigate transmitted sounds. Each of the microscopy bays are 16 ft. x16 ft. and 18.5 ft. tall and have both radiant Figure 2.1 – right) and ultra-low-flow HVAC to keep thermal stability to better than one degree Fahrenheit. This facility exceeds the VC-F (1.56 microns a sec) vibration level which is a requirement on some of the highest resolution microscopes. A key take-away from the site visit for the team was the need to ensure that all mechanical support systems in the building are adequately damped. It is unlikely that CINT will be able to implement the structural changes needed to replicate ASU's capabilities.

3. NNSA VIBRATION TEST

To determine the highest level of vibration induced during the construction of the NACP, Amec Foster Wheeler was commissioned with performing a simulation of the excavating, backfilling and compaction that will be used during construction. The full report, as provided from Amec Foster Wheeler, is included in Appendix IV of this SAND. Figure 3.1 is a photo of the Cat CS74B used during the compaction portion of the test and Figure 3.2 is the actual test area after backfilling and compaction was completed. Figure 3.3 is the aerial view of the trenching area with the locations of the vibration sensors marked.

Figure 3.1. Cat CS74B Vibratory Soil Compactor

Figure 3.2. Photo of Backfilled and Compacted Test Strip

Vibration monitors were placed at the corners of the CINT facility. Unfortunately, the choice of monitors did not allow for the monitoring of vibrations down to VC-E (3 microns / sec). Rather, the threshold for the sensors was 101 microns / second. Despite that limitation there were still significant vibrations observed during the compaction portion of the test. The maximum vibrations recorded near the APF were approximately 380 microns / second and 127 microns / second by the TEMs.

The manufactures of the APF and the TEM indicated that they do not expect any permanent damage to the systems from experiencing the observed level of vibration. However, neither of the tools will be operable during the compaction events. As NNSA representatives from the construction team estimated that the trenching and compaction process could last up to 6 months, there will be a substantial impact on operations during that period.

As there were no vibration measurement taken below the 101 micron/second threshold of the system it is possible that the excavation could also induce vibrations in excess of VC-E. Additional tests are required to make this determination.

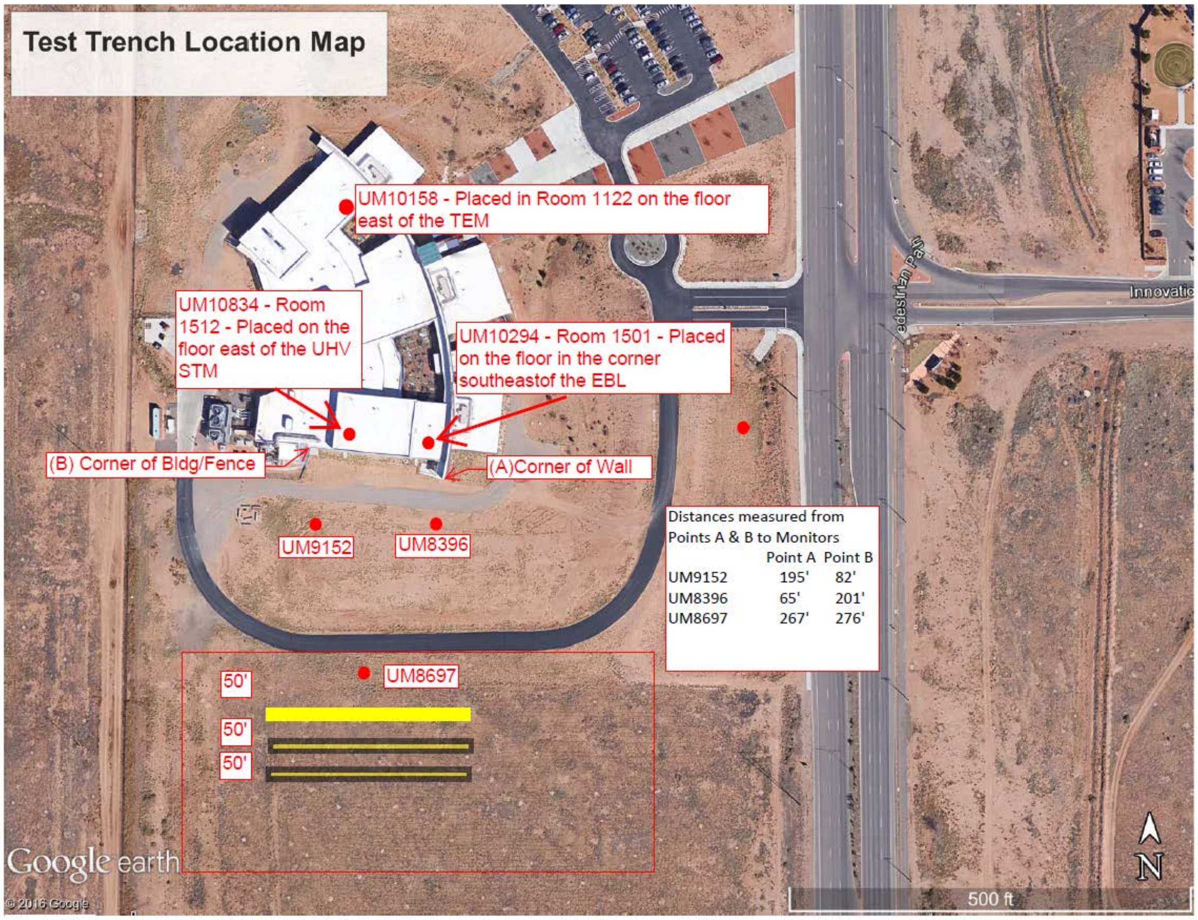


Figure 3.3. Aerial View of Test Area and Location of Sensors

4. CINT'S NEW VIBRATION MONITORING SYSTEM

To improve CINT's ability to measure vibrations and to allow continuous monitoring, a standalone vibration monitoring system was permanently installed within the CINT facility. The vibration monitoring system was purchased by Sandia National Laboratory and is intended to remain in place and operational indefinitely. The system was operational the week of September 25th and was used in the vibration tests presented in sections 5 and 6 of this SAND report. Doug Pete, a principle level technologist in org. 1881, has taken primary ownership of the system and is charged with maintaining the system and monitoring for excursions.

4.1. Vibration Monitor System Description

The vibration monitoring system installed in CINT is a four channel vibration monitoring system that consists of four Wilcoxon Research Model 731A seismic accelerometers, 10 V/g. The sensors are placed on the floor, in a vertical orientation, in the laboratory rooms listed in Table 4.1.1. and Figure 4.1.1.

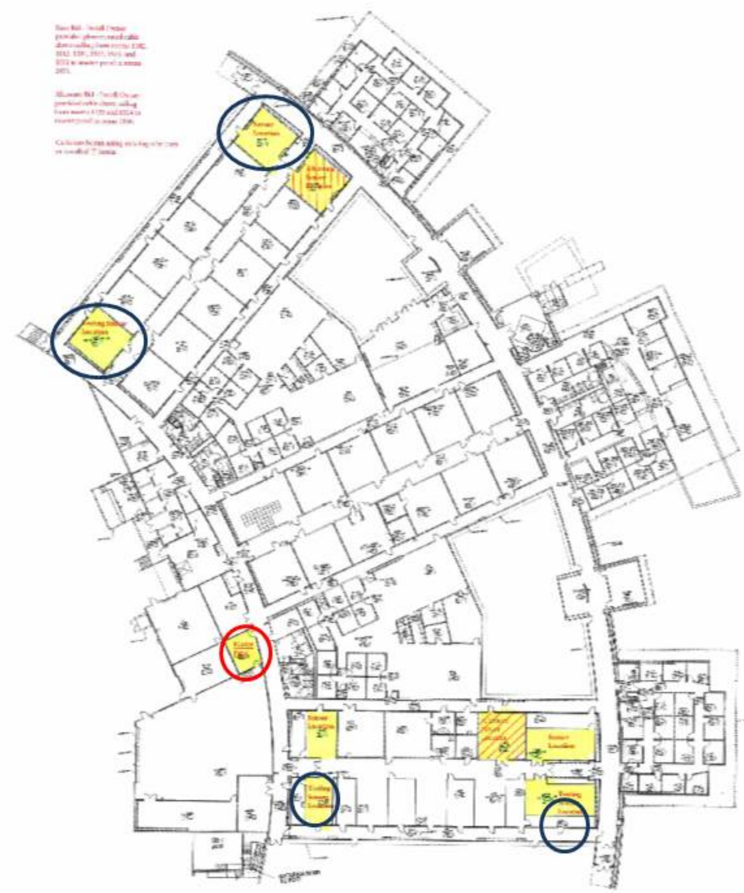
Table 4.1.1. Seismic Accelerometer Locations

Channel	Number Serial	Room Number	Room Description
1	10554	1102B	Tecnai F30 TEM Lab
2	10551	1522A	Lithography Chase
3	10552	1112A	Quantum Transport Lab
4	10553	1532	Flex Bay

The sensor signals are direct wired to a dynamic signal analyzer. The analyzer is an 8-channel, Crystal Instruments, Spider 80x Box. Only channels 1 to 4 are active and populated. The analyzer averages data for 60-seconds from each sensor, then transfers the resulting auto-power spectrum to the host computer memory for storage.

Four additional cables have been placed above the ceiling to the four remote corners of the facility in anticipation of monitoring for external construction activity. In addition, four power unit/amplifiers, Wilcoxon Model P31, with cables are available to relocate the accelerometers anywhere in the facility and view the signal data with any low-frequency portable dynamic-signal analyzer.

Details of the Wilcoxon Research Model 731A seismic accelerometers and the Crystal Instruments, Spider 80x Box can be found in Appendix IV.



Red circle indicates location of the Spider 80x Box, and the blue circles indicate the location of the sensors.

Figure 4.1.1. Accelerometer Locations

4.2. Background Vibration at CINT

By looking at the continuously acquired vibration data over a several day period of normal CINT operations, we found that the nominal background vibrations are better than VC-E at all four sensor locations. We attribute this to the care taken in building site selection and facilities engineering of the building physical plant, such as vibration isolation of the building HVAC equipment. The residual vibrations measured were primarily due to CINT-owned vacuum pumps and compressors that have not been specifically isolated from the concrete floor slab. These vibration sources are localized in the building and are completely extinguished at the distance of the next nearest sensor.

5. THIRD CINT VIBRATION STUDY

To further understand CINT's sensitivity to vibrations, Machine Dynamics, Inc. was commissioned to perform two experiments in the fall of 2017. These test used the newly installed vibration monitoring system described in the previous section to record all of the seismic data. The testing was done in two parts. The first part of the test measured the high-frequency response (Section 5.1) and the second part measured the low frequency response (Section 5.2). The full report from these tests are included in this document as Appendix VI, with sections 5.1 and 5.2 being excerpts from the study.

5.1. Impact Test – High Frequency Response

Figure 5.1.1. Portable Hardness Tester

A portable hardness tester (Figure 5.1.1) was used to generate a 1,500 Kg impact onto a steel plate. This testing was done outside the northeast corner of the facility. The closest sensor in Room 1102, SPM Lab, was observed while the hardness tester impacted the steel plate several times. With the steel plate on dirt, no discernible shock pulse was visible above the normal background environment. With the steel plate on the concrete walk outside the northeast door, shock pulses were visible at levels approximately three times the normal background environment.

The conclusion from this impact testing is that the dirt around the CINT Facility provides a good isolation barrier to impacts that create high-frequency vibration.

5.2. Dump Truck Test – Low Frequency Response

Figure 5.2.1. Photo of Dump Truck Used in Vibration Test

A fully loaded dump truck was commissioned to drive around the south side of the CINT facility (Figure 5.2.1). The truck was loaded with 23 tons of rock and dirt for a total weight of 80,500 pounds. Figure 5.2.2. is an aerial view of the route traveled during the tests runs. On the south side access road, one half of the tires were on the pavement, while the other half traveled on the uneven dirt adjacent to the pavement. The dump truck traveled the route three times, during which data from the four seismic accelerometers installed in the CINT facility was digitally recorded. The most active signals, when the dump truck was rolling close to the building, were captured in a peak-hold averaging mode. The truck activity created a significant low-frequency motion at 3.0 Hz plus broadband activity between 10 to 30 Hz. In the peak-hold averaging mode, these vibrations exceed the 3.0 microns/sec limit. In the exponential-averaging mode from the Crystal Instruments box, the same vibrations are visible but the levels remain well below 3.0 microns/sec.

Figure 5.2.2. Route of Dump Truck for Vibration Test

The 3.0 Hz vibration is the one likely to induce the larges impact on the APF and TEMs. It was the conclusion of the study that there is a resonant coupling between the seismic waves generated form the truck and the CINT structure, possibly be the roof. The 3.0 Hz vibration was visible at all four sensor locations, even those on the north side. The north side sensors did not display any significant vibrations in the 10- to 30-Hz range during the truck motion. The spectral pattern was very similar to normal background motion with a very small peak at 3.0 Hz.

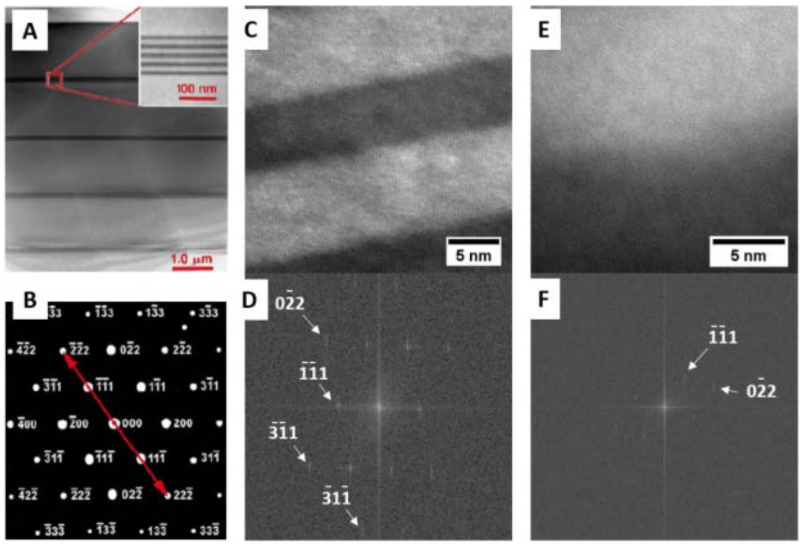
The following five specific conclusions were made based on this study:

1. The CINT Facility, building 518, is relatively insensitive to external vehicular movement on Eubank.
2. Heavy truck movement (80,500 pounds) on unpaved grounds within 100 feet of the building will marginally exceed the VC-E limit of 3.0 microns per second.
3. Diesel engines, whether on construction vehicles or portable generators, will have a negligible impact on the facility if kept more than 200 feet away.
4. High frequency impact motion from construction activity, like hammering, pneumatic tools, or grinding, is not likely to affect the facility.
5. Low frequency ground pounding from compaction could be troublesome.

5.3. Instrument Resolution Tests during Dump Truck Test

On Saturday October 7th after 10:00 am, while the Dump Truck filled with 80,000 lbs of rocks was traversing the route shown in figure 5.2.2., the Electron microscopes within CINT were being used in high-resolution mode to observe any impact. At 9:30 am that day, the Tecnai F30 (lab 1102) was aligned in STEM mode for the test, though within 2 minutes of the first drive-by, the fan on the graphics card for the control PC failed. At this point, around 10:12 am, a MAG*I*CAL standard sample (Figure 5.3.1. a-b) was loaded into the Titan ETEM (lab 1122).

As there wasn't time for alignment, the sample was imaged in STEM mode using the alignment from the previous day. This hasty change, introduced carbon contamination to the sample during imaging, which degraded the image quality during continuous capture, though should not have been significant enough to remove high-spatial resolution information from the image. In addition, this system was not chosen originally, as due to its recent installation, there was a significant source of carbon to cause rapid contamination.

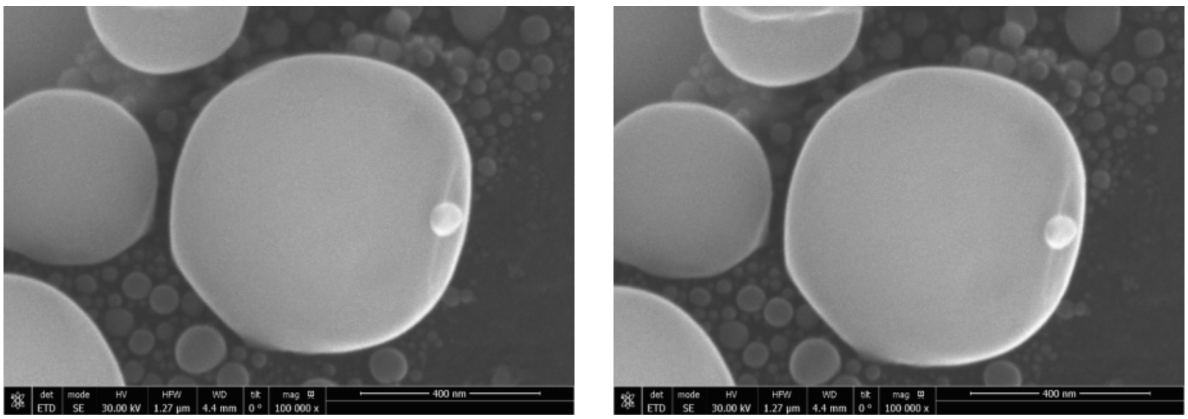


*High-resolution Scanning Transmission Electron Microscope Dark-Field images of MAG*I*CAL standard sample. (a) Configuration of [011] Si crystal, with ~10 nm features and (b) diffraction patterns for resolution determination. DF STEM images when the truck was stopped (c) and during travel on dirt next to the CINT South wall (e), with corresponding Fourier Transforms of the images (d) and (f), respectively.*

Figure 5.3.1. Dump Truck Vibration Impact on High-Resolution STEM Imaging

Initial images were acquired on the [011] Si standard sample, after the crystal was tilted on to zone axis. Images were scanned at a slow rate of 40 seconds per image, with some sample drift observed due to thermal variation of the holder and the column within the microscope. Stable imaging was achieved when the dump truck was stationary at 10:40 am, shown in Figure 5.3.1.(c). The corresponding Fourier Transform of the image is shown in Figure 5.3.1.(d), where intensity pattern, similar to a diffraction pattern may be observed to determine the spatial resolution obtained within the image. In the case where the truck was stationary, information from the [311] planes in Si were resolved, corresponding to 1.64 Å. During the second drive-by of the dump truck at 10:49 am, on the dirt next to the integration laboratory on the south side of the CINT building, Figure 5.3.1.(e). This image shows decreased clarity in the crystal lattice, which is quantified in the Fourier transform of the image shown in Figure 5.3.1.(f). During the motion of the dump truck on the dirt, almost 10 images were acquired, in which none provided spatial resolution beyond the [022] crystal plane, corresponding to 1.9 Å. It should be noted that while the dump truck was stationary between tests and at the end of the experiment, images represented in Figure 5.3.1.(c) were obtained. This test identified that the vibrations transferred through the dirt under the building by the movement of a dump truck filled with 80,000 lbs of rock is significant enough to limit the high-spatial resolution imaging capability of the TEMs.

During the dump truck test, images were also acquired on a scanning electron microscope (SEM) located in the Integration Lab on the south side of building. The SEM was operated at a magnification routinely used for inspection of fabricated devices. The test images are shown in Fig. 5.3.2. No discernable impact can be seen at this resolution. No images were acquired at the highest resolution during the test.



Left – Before test, Right – During test.

Figure 5.3.2 Dump Truck Test Impact on SEM Imaging

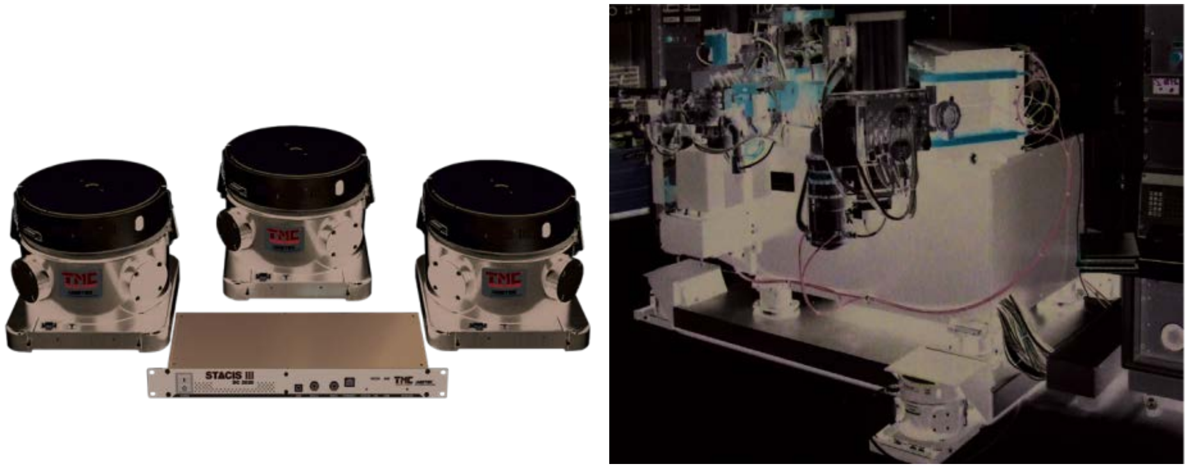
6. TOOL-BASED VIBRATION REDUCTION SYSTEM

6.1. System Description

After discussions with the vendor of CINT's TEMs, FEI, we contacted eQuestus Corporation, Mesa AZ, to evaluate a piezo-actuated active vibration dampening system. This system was used by FEI to limit construction vibrations on the TEM's located at Intel's Ronler Acres facility as well as the University of Portland where it was used to dampen out vibrations from the trolley car line that ran outside the building.

The specific system recommended by the vendor was the TMC STACIS III, which "employing advanced inertial vibration sensors, sophisticated control algorithms, and state-of-the-art piezoelectric actuators, STACIS cancels vibration in real time by continuously measuring floor activity, then expanding and contracting piezoelectric actuators to filter out floor motion."

The system shown in the figures below consists of three active vibration dampening legs (left) that support a 4" thick steel slab on which the tool rests (right).



Active isolation legs (left image), system installed on a SEM (right image).

Figure 6.1. TMC STACIS III Vibration Isolation System

Table 6.1. STACIS III System Performance

Active degrees of freedom	6
Active bandwidth	0.6 to 150 Hz
Natural frequency	Passive elastomer: 18 Hz, Effective active resonant frequency: 0.5 Hz
Isolation at 1.0 Hz	40% - 70%
Isolation at 2.0 Hz and above	90% or better
Settling time after a 10 lb (4.5 kg) step input (10:1 reduction)	0.3 sec
Internal noise	<0.1 nm RMS
Operating load range per isolator (different passive mounts required) Isolator overload safety factor	400 - 4,500 lb (182 - 2,045 kg) > 2:1
Number of isolators	3 or 4 typical
Stiffness (1,000 lb/454 kg mass) (typical middle capacity isolator)	40,000 lb/in. (73 x10^5 N/m)
Magnetic field emitted	< 0.02 micro-gauss broadband RMS

The team interviewed a user of the system and the reviews were mixed. The users did find improved resolution, but there were complexities in using the system that occasionally cause instability in the tool. Specifically, they observed that the active vibration dampening system would occasionally induce instability when trying to counteract the passive dampening in the tool. In their experience, this complexity could be overcome.

6.2. Calculated Vibration Reductions

Data from the second CINT vibration test (see Section 5 & Appendix VI) points to the conclusion that active damping tables will provide meaningful mitigation for some construction noise sources, such as truck traffic.

Appendix VI shows vibration noise spectra before and during the “dump truck test” in which a loaded dump truck was driven around the vicinity of CINT. The truck caused floor vibrations in the APF lab exceeding both tool manufacturer specifications, Table 1.4.1, and VC-E (3 µm/s). The strongest noises were measured at 3 Hz with a vertical floor velocity of 5.6 µm/s (peak) with additional broadband noise in the range 10-30 Hz vertical floor velocity of 6 µm/s (peak at 23 Hz), exceeding VC-E. While the dump truck was driving, the peak floor vibration velocities were 2-5 times larger than normal in these frequency ranges.

To estimate the benefit of the damping tables, we multiplied the vibration spectra by the tables transmissibility function, Figure 6.2. The table transmits only about 0.05 of the noise signal at 3Hz, so the 5.6µm/s peak at 3Hz would be suppressed safely within manufacturer specifications and VC-E. The 10-30Hz broadband noise (6 µm/s peak) would be suppressed by a factor of around 0.03, driving peak noise well below VC-E, and even the present vibration noise levels.

It is worth nothing that the tables may not adequately damp out all construction noises. For example, during the first vibration test initiated by NNSA, compaction activities caused ~380 µm/s floor velocities, which would be suppressed by a factor of 0.03-0.05, to around 10-20 µm/s, which would exceed manufacturer spec’s in the 1-20 Hz range (Table 1.4.1), as well as considerably exceeding VC-E and present noise levels.

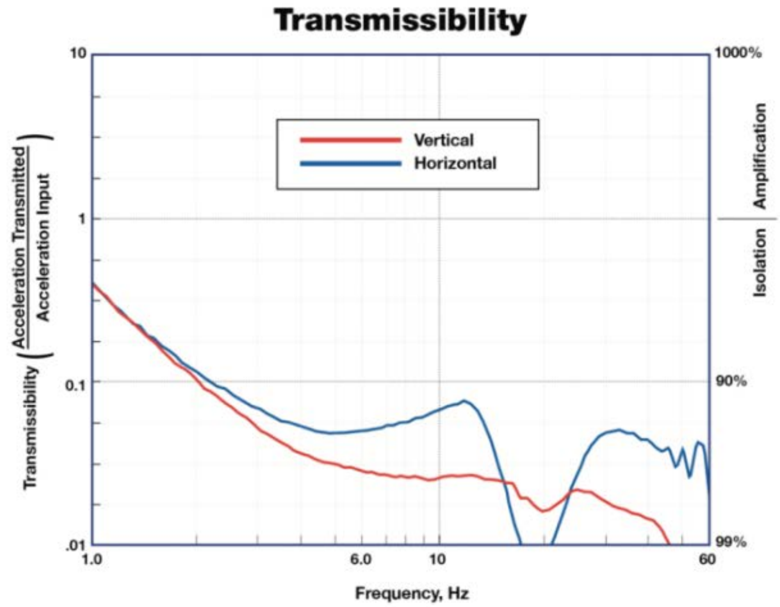


Figure 6.2. Plot of the Expected Transmissibility for the STACIS III System

6.3. System Purchased

Given the limited time available before construction begins for the NACP facility and the anticipated impacts of construction, it was decided that a TMC system should be purchased for the APF system. This decision was made based off of two main factors: 1 – the APF was the most sensitive of the tools at CINT and it is located on a normal slab (12”) with minimal isolation, and 2 – no room modifications are needed to install the system.

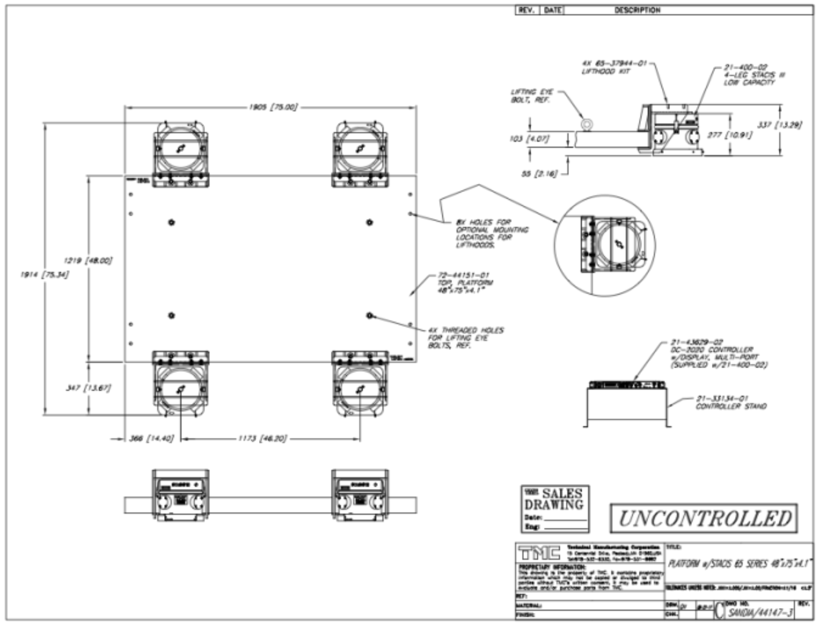


Figure 6.3. Blueprint of MTS System Purchased for Atomic Precision Fabrication System

A STACIS III system was purchased and delivered in late September 2017. The system will be installed and actual performance evaluated in January of 2018. The delay in installation is driven by customer deliverables, which prevent the system from being taken offline for the 3-4 weeks needed to perform the installation.

It was also determined that CINT should not purchase STACIS III systems for the transmission electron microscopes at this time, as extensive room modifications are needed to accommodate the increase in height of the systems. Pending the outcome of the planned installation in January 2018 of the system on the APF, this decision will be revisited.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Key Findings

- CINT is very quiet, better than VC-E.
- Eubank traffic does not cause CINT to exceed VC-E.
- Standard deliveries to CINT, including semi-trailer based deliveries, do not cause vibrations significantly in excess of VC-E at the tools.
- No long term vibration impacts from the NACP are anticipated, provided that appropriate vibration isolation of the NACP building facilities are installed during construction.
- Soil compaction during the construction of NACP will cause vibrations approximately 100 times greater than VC-E, which will render the TEM and AFP tools inoperable during those times.
- We were not able to determine if trenching will also cause vibrations in excess of VC-E.
- Tests indicated that standard construction traffic will not substantively impact CINT's operations. Only the TEMs operated at high resolution had any notable degradation of capability.
- The committee also believes that other construction activities will likely not substantively impact CINT's operations.
- Isolation tables will help reduce vibrations. However, with only a 70% reduction of low frequency vibrations (<10Hz), they will likely not be effective during the compaction or trenching.

7.2. Recommendations

A general comment from the committee was the obvious statement that it is easier to reduce vibrations at the source, rather than working to reduce them after they have been created. If the vibrations must be created, then increasing the distance between the source and the impacted systems is the next best option.

For the NACP Construction Team:

- NACP should evaluate alternative construction technique that does not require vibration compaction of the soil or perform the compaction. If that is not an alternative, then NACP should consider lower force vibration compaction processes. For example, New York City requires low noise jackhammers.
- The NACP construction team should route heavy construction truck traffic at the furthest possible distance from CINT, e.g. as far south on the NACP lot as possible to minimize impact on the APF and TEM.
- Truck traffic, such as trash service, is not anticipated to induce vibrations in excess of VC-E.
- Evaluate the use of a "sand break" to dampen the construction vibrations transmitted to the CINT facility if the source vibration can not be reduced.
- Limit days/hours in which compaction can be done to standard business hours.
- Develop a clear communication channel between the construction team and CINT, particularly during the trenching and compaction phase. CINT needs at least one week

advance notice of planned construction activities. One month's advance notice is better due to the majority of visitors being from out of town and they need to schedule travel.

For CINT management:

- Schedule the majority of TEM and APF users to weekends and nights during the trenching and compaction phase of construction.
- Change Foreign National TEM users access from 6am to midnight to 24 hour a day access to the TEMs during the trenching and compaction period. This will require a corporate exemption, but will reduce the loss in productivity of CINT.
- Develop a clear communication channel between the construction team and CINT. Work with out-of-town users to provide the greatest possible advance notice and prevent wasted travel.

7.3. Other Considerations

Though this team did not specifically evaluate possible impacts on CINT from the construction of NACP other than vibrations a few areas that the team identified for consideration are listed below.

- Positioning of transformers can be critical as they will typically have strong field and weak field directions. The strong fields have been observed to impact the sensitive electronic equipment such as the qubit's fabricated and tested at CINT.
- Welding in the vicinity of TEMs has also been observed to induce astigmatism issues. This is best solved through minimizing the use of the TEM while welding is occurring. Distance and appropriate electrical separation is also beneficial to reduce these effects

APPENDIX I: SFO DIRECTIVE TO NTESS TO PERFORM VIBRATION STUDY

Department of Energy
National Nuclear Security Administration
Sandia Field Office
P.O. Box 5400
Albuquerque, NM 87185

MAY 09 2017

Dr. Susan J. Seestrom
Associate Laboratories Director
Advanced Science & Technology
Sandia National Laboratories
P.O. Box 5400, MS-0351
Albuquerque, New Mexico 87185

Subject: Advisory Panel on National Nuclear Security Administration Albuquerque Complex Project Impacts on Center for Integrated Nanotechnologies Core Facility

Dear Dr. Seestrom:

The National Nuclear Security Administration (NNSA) Administrator has identified the construction of the NNSA Albuquerque Complex Project (NACP) as his number one goal, and, consequently, this initiative has become a top priority for the Sandia Field Office (SFO). The Department of Energy, Office of Science/Office of Basic Energy Sciences (BES) has expressed concern of potential impacts on the Center for Integrated Nanotechnologies Core Facility (CINT) during the construction and operations of the proposed NACP, which will be located directly south of the CINT facility. The SFO understands the important work performed by the CINT facility, and wants to minimize the impacts to CINT during construction and operations of the NACP.

The SFO requests National Technology and Engineering Solutions of Sandia, LLC (NTESS) form an advisory panel, comprised of subject matter experts, to look at potential impacts to CINT, and identify mitigation strategies for NNSA to consider with regard to the construction and operations of the NACP. The SFO requests that NTESS invite a representative from BES to serve on this advisory panel. The SFO also requests NTESS to look at all mitigation strategies, to include engineering, and administrative controls that can be implemented with respect to the site, facility (CINT), and operations (work scheduling and planning). Please consider strategies associated with the construction and operations of the NACP, as well as any future development (i.e., Kirtland Air Force Base, NNSA, City of Albuquerque) that may occur in the area that could potentially impact CINT operations. By November 1, 2017, please provide the SFO with recommended mitigation strategies associated with the construction and operations of the NACP, the operations at the CINT, and future development in the area.

The SFO is committed to working closely with all parties involved to support open and direct communication, and to ensure that all parties' interests are considered. Recognize that this does not mean there will be no impact; but rather, the SFO will work closely with other parties to minimize impacts. Construction of this project may start as early as August, 2018, and it is expected that the foundation construction will last between six to 12 months; however, the major impact period is expected to only last approximately eight to 10 weeks. Based on the aggressive construction schedule, it is imperative that any issues be identified and resolved as soon as possible.

SFO, NTESS, and BES all have their own individual interests; however, we must work together on this common goal. If you have questions, please contact me at (505) 284-6668 or Doris Sandoval-Tellez of our staff at (505) 845-5673 or Doris.Sandoval-Tellez@nnsa.doe.gov.

Sincerely,

James W. Todd
Assistant Manager for Engineering

cc:
Dawn Harder, NA-APM-20
Jeffrey Harrell, SFO/OOM
Michael Duvall, SFO/OOM
Shirley Mondy, SFO/CMT
733234

APPENDIX II: CINT PRE-CONSTRUCTION VIBRATION REPORT

SANDIA NATIONAL LABORATORIES

CENTER FOR INTEGRATED NANOTECHNOLOGIES
CORE FACILITY

Exhibit D STUDY OF GROUND VIBRATION AND AIRCRAFT NOISE AT PROPOSED SITE FOR THE CENTER FOR INTEGRATED NANOTECHNOLOGIES (CINT) CORE FACILITY, ALBUQUERQUE, NM. Dated 18 October 2002

COLIN GORDON & ASSOCIATES

STUDY OF GROUND VIBRATION AND AIRCRAFT NOISE AT PROPOSED SITE FOR THE CENTER FOR INTEGRATED NANOTECHNOLOGIES (CINT) CORE FACILITY, ALBUQUERQUE, NM

Prepared by: **Michael Gendreau, Jason Ho, and Hal Amick**
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18 October 2002

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1. Introduction and Executive Summary

This study was undertaken to determine the suitability, insofar as ambient vibration and noise is concerned, of a site near the Sandia National Laboratories complex in Albuquerque NM for the location of the Center for Integrated Nanotechnologies (CINT) Core Facility.

Ambient vibration (due to many industrial and traffic sources near and far), as well as vibration generated by proximate ground transportation sources, was examined on the proposed CINT site. The broadband ambient vibration amplitudes are generally very low. However, traffic on the adjacent Eubank Boulevard has a greater potential to impact to the site. The proximity of the road should be a major consideration in the selection of the CINT building position and layout on the site, if the lowest possible vibration environment is required.

The site is a moderately difficult one with regard to air traffic noise and the potentially stringent noise requirements for nanotechnology work. The building shell will have to provide a significant amount of transmission loss. For the most stringent laboratories, it may be best to avoid windows entirely. Air intakes and exhausts may require special attention to avoid flanking.

2. Measurement Conditions

The site, situated southwest of Southern Avenue SE and Eubank Boulevard SE, is currently undeveloped. It is surrounded by various undeveloped and developed land uses, including commercial, residential, and government. Kirtland Air Force Base and the Albuquerque International Airport are located nearby, to the southwest.

Michael Gendreau of Colin Gordon & Associates visited the proposed CINT Core Facility site on 27 August 2002 to conduct the vibration portion of this study. There is currently a condominium construction project ongoing across Eubank. Light to medium construction activity at this site was not measurable on the CINT site.

In addition to the ambient vibration study of this site, the transient effects of local traffic were examined. The busiest local roadway is Eubank Boulevard, passing along the east edge of the site. The traffic along this road is medium to heavy. It is used primarily by automobiles, but also by medium weight delivery trucks and occasional heavy vehicles. Further description of these vibration sources and measurement data are given in Section 5 of this report.

The aircraft noise measurements were carried out by Jason Ho of Colin Gordon & Associates on 10 and 11 September 2002. The weather was partly cloudy with occasional rain. The temperature was about 75° F (24° C). There was a strong wind on 10 September (perhaps 11-15 mph East-West), and no wind on 11 September. The measurements were made near the center of the proposed site.

3. CINT Vibration and Noise Criteria

Vibration criteria have not yet been selected for the CINT building. It is expected that the vibration requirements will be very stringent in certain areas, as appropriate to the sensitive work to be carried out in the facility. For reference, vibration criteria currently in use at other highly sensitive facilities are described below.

The commonly used vibration criterion curves for sensitive equipment and processes[1] are described in Exhibit A. In contemporary use, these curves are often modified at low frequency, extending the constant velocity amplitude portion of the curve down to 1 Hz. In this report, for reference we compare the measurement data with the most stringent of these curves, VC-E. This is a typical criterion for the most vibration-sensitive floors in nanotechnology facilities. However, much of the research equipment in this facility can function in a less stringent environment. For the CINT facility, the vibration criteria will be verified once details about the research tool set are known.

Similarly, for noise, criteria have yet to be developed for the most critical laboratories. For traditional laboratories, criteria of NC-45 (with fume hoods) and NC-40 (without fume hoods) are common, but it is not unusual to require much more stringent criteria for very sensitive nanotechnology work, perhaps on the order of NC-25.

Table 1 lists typical noise criteria for some common room functions.

[1] "Generic Criteria for Vibration-Sensitive Equipment," Colin G. Gordon, *SPIE Proceedings* Volume 1619, Pages 71-85, 1991. These criteria are also referenced in Institute of Environmental Sciences (IES) Contamination Control Division Recommended Practice 012.1 "Considerations in Cleanroom Design" IES-RP-CC012.1.

Table 1: Typical Room Noise Criteria (NC)[2]

Room Function	Recommended NC Range
Clean rooms	55-60
Computer rooms	45-55
Light maintenance shops	45-55
Shop classrooms	40-50
Corridors and public circulation areas	40-50
Laboratories with fume hoods	40-50
Large offices	35-45
Open-plan offices	35-40
Lab support spaces	30-40
Lab equipment corridor	30-40
Private offices	30-40
General classrooms	30-40
Libraries	30-40
Executive offices	25-35
Large lecture rooms	25-30
Conference rooms	25-30
Auditoria	25-30

[2] This compilation is based on the following references, and others: (1) *ASHRAE HVAC Applications* Chapter 42 Sound and Vibration Control (1991), (2) Howard F. Kingsbury "Review and Revision of Room Noise Criteria" *Noise Control Engineering Journal* 43-3 May-June 1995, (3) American National Standards Institute *Criteria for Evaluating Room Noise* ANSI S12.2-1995, (4) Robin M. Towne et al. "The Changing Sound of Education" *Sound and Vibration* January 1997.

4. Measurement Methodologies and Instruments

Vibration measurement methodologies. The data were acquired using a measurement bandwidth of 0.25 Hz and the Hanning windowing function, for an effective bandwidth of 0.375 Hz. The measurement frequency range is 0 to 100 Hz. Typically we quantify the vibration velocity at a single location on the basis of the RMS linear average (energy average) of multiple sequential samples acquired over the period of about 20 seconds. This is an adequate statistic for environments that are statistically "stationary," dominated by steady-state random processes. In cases where a site is impacted by short-term transient events, such as passing trucks, we may, depending on the circumstances, measure also the "maximum RMS" (on some signal analyzers called "peak hold") amplitude. This amplitude is substantially higher than the linear average amplitude.

Noise measurement methodologies. The aircraft noise data were measured with an octave band analyzer using both the L_{eq} and L_{max} methodologies[3]. The microphone was set upon a tripod at a height of about 5 feet above the ground. At the same time, the overall A-weighted noise was recorded using continuous monitors, in various statistics (L_{max}, L_{eq}, $L_{(X)}$,[4] etc.).

Measurement instruments. The vibration and noise measurements were carried out with the following instruments:

Accelerometer - Brüel & Kjær Model 8318 (WH 2146)
Charge Amplifier - Brüel & Kjær Model 2635
Vibration Signal Analyzer - Rion Model SA-77

Microphone - Rion Model UC-53
Octave Band Sound Level Meter - Rion Model NA-29E (ANSI Type 1)
Continuous Noise Monitor - 2 of Larson Davis Laboratories Model 812 (ANSI Type 1)

together with the associated calibration systems, cables, connectors, etc. The calibration of the measurement instruments, which uses reference standards traceable to the US National Institute of Standards and Technology (NIST), is performed yearly and was verified in the field at the time of the measurement survey.

[3] The equivalent-continuous sound level, L_{eq}, is the level of steady (non-varying) sound which, for the measurement period, has the same sound energy as the time-varying sound. The L_{max} level is the maximum rms noise level during the measurement period.

[4] The statistical centile level, $L_{(X)}$, is the sound level exceeded X percent of the time during each measurement period. The $L_{(90)}$ level is often identified with the true site "ambient" level—in the absence of intruding intermittent sources.

5. Presentation and Discussion of Vibration Data

Vibration measurement locations. Vibration measurements were taken upon a steel platform attached to a spike driven about 8 inches into the soil at 7 locations distributed over the site. The specific locations of these measurements were determined by Colin Gordon & Associates to represent the ambient vibration environment on the site, with some locations selected to determine impact from nearby sources of vibration (roads and adjacent buildings). Table 2 lists the distance of the locations from Eubank Boulevard (these locations are various distances from Southern, extending over the north-south range of the site):

Table 2: Measurement Location Distance From Eubank Boulevard

Location	Distance (ft)
1	100
2	210
3	310
4	(not used)
5	550
6	> 700
7	> 700
8	160

Ambient vibration measurement data. Figures 1, 2, and 3 show the ambient vibration data measured on the proposed CINT site in the vertical, north-south horizontal, and east-west horizontal directions, respectively. In the frequency spectrum plots the data are presented in two formats as follows:

(a) Narrowband spectra having a fixed bandwidth, throughout the 0 to 100 Hz frequency range, of 0.375 Hz. The value of these plots is primarily "diagnostic." The plots show the extent to which pure tones (most often generated by the rotating shafts of machinery) and resonances influence the vibration. These plots can help in identifying sources of vibration.

(b) One-third octave band spectra having a bandwidth of twenty-three percent of each band center frequency. This is the format of some of the vibration criterion curves described in Exhibit A.

In all cases, the ambient vibration data are well within the VC-E criterion, which generally indicates that the site is quite acceptable for the proposed use.

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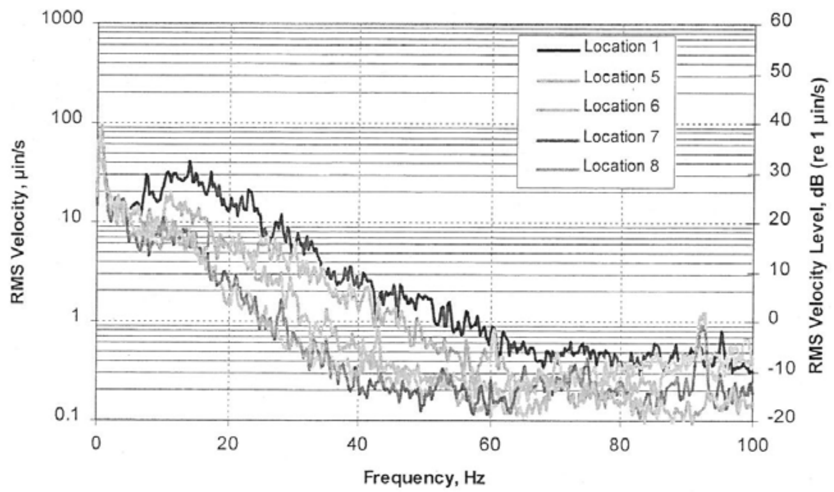
Figure 1: CINT Core Facility Site Vibration Survey - 27 August 2002
Ambient Site Vibration, Linear Average RMS, Vertical

a) Narrowband (Bandwidth = 0.375 Hz)



b) One-Third Octave Band

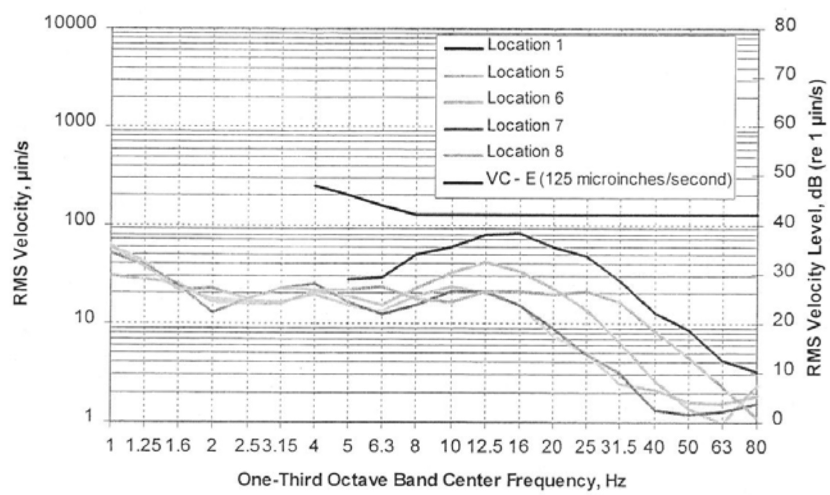


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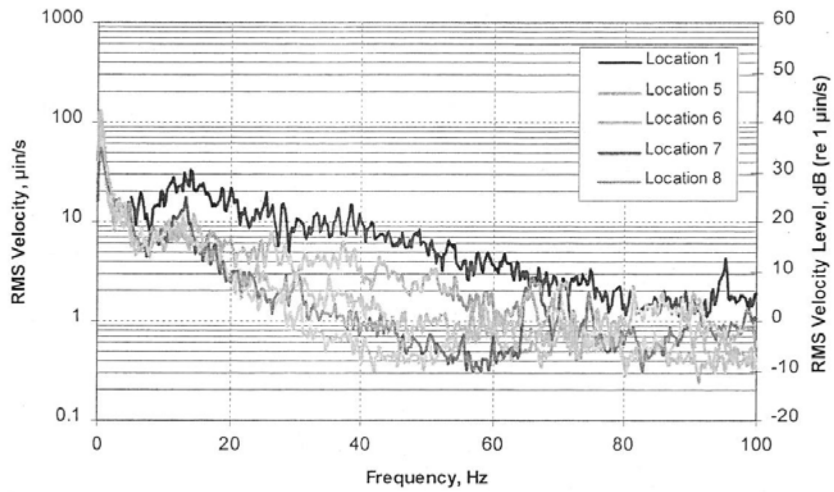
Figure 2: CINT Core Facility Site Vibration Survey - 27 August 2002
Ambient Site Vibration, Linear Average RMS, Horizontal (North-South)

a) Narrowband (Bandwidth = 0.375 Hz)



b) One-Third Octave Band

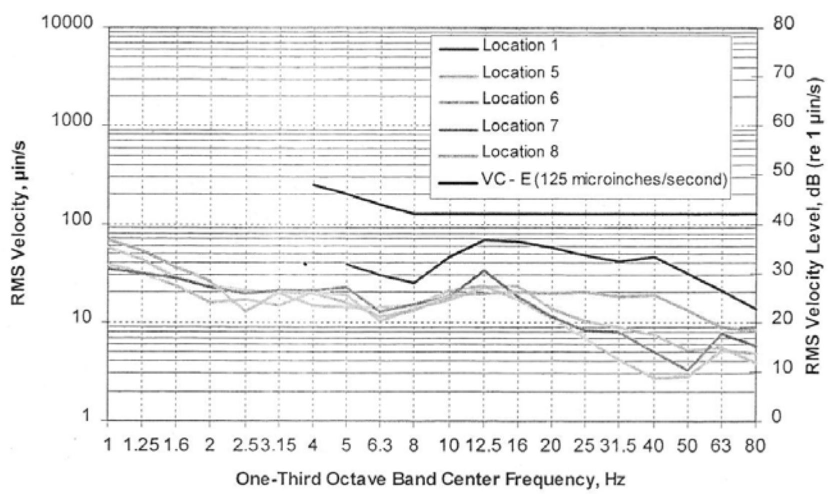


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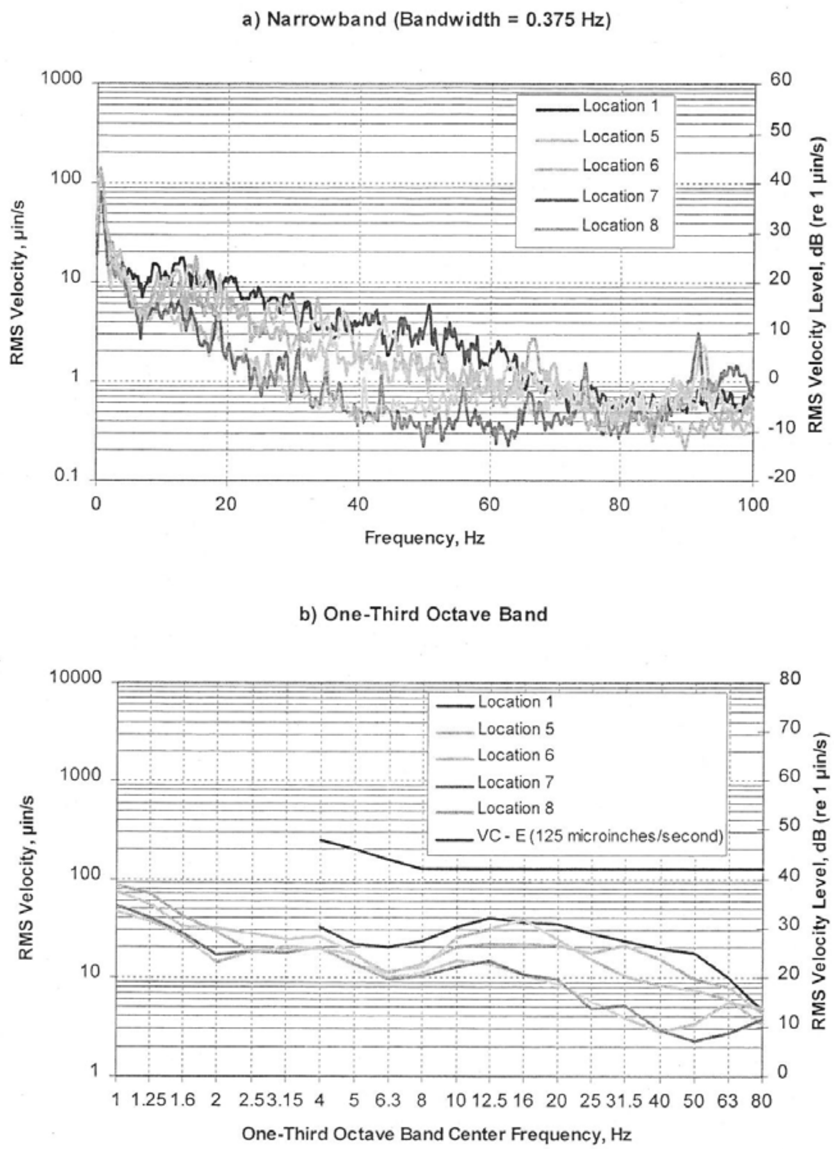
Figure 3: CINT Core Facility Site Vibration Survey - 27 August 2002
Ambient Site Vibration, Linear Average RMS, Horizontal (East-West)



The highest amplitudes were measured at Location 1 (about 100 feet from Eubank at the east side of the site), and the lowest at Locations 6 and 7, which are closer to the western side of the site. It is clear that traffic influences the ambient vibration, as a function of distance from the road. The increase due to traffic is primarily in the 10 to 30 Hz frequency range.

Traffic vibration. Based on the results of the ambient data, we studied the traffic vibration impact in more detail. Eubank Boulevard was quite busy at the time of our visit, with approximately 20 light vehicles (automobiles, SUVs, pick-ups) and 1 heavy vehicle (tank trucks, container trucks, flatbeds, dump trucks, etc.) passing by per minute. We measured the maximum RMS vibration level with different types of vehicles passing at different distances. With this method, the highest vibration level due to the short term transient event is retained. This is a conservative representation of the vibration impact, since some research processes and tools may be somewhat forgiving of short term transient impacts. Generally, the highest vibration amplitudes are a function of vehicle weight and speed. For example, Figure 4 shows the influence of vehicle speed on the data. In this case, the same loaded flatbed passed by Location 8 twice at different speeds.

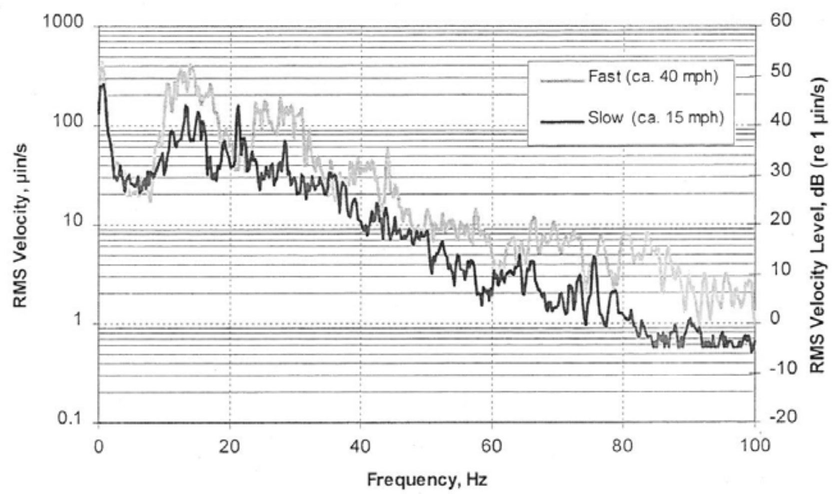
Figures 5 and 6 show the impact versus distance from light and heavy vehicles, respectively, at various frequencies. As expected, the impact from heavy vehicles is greater (but less frequent), and the high frequency vibration is attenuated more quickly than the low frequency components. Generally, variations or spread in the data points at a particular distance are due to variations in the vehicle speed and weight, the latter only roughly accounted for in the segregation of the data into two figures.

In summary, at all frequencies, the light vehicle vibration drops below VC-E at approximately 250 feet from Eubank, and the heavy vehicle vibration (on average) meets VC-E at about 550 feet. These data give some indication of the required CINT building set-back distance from the road, but it must be borne in mind that these are maximum RMS data. The "equivalent continuous" linear average RMS response from sporadic traffic, which is what we would normally compare with certain of the criterion curves, would be significantly lower. In any case, it is clear that the proximity of vehicular traffic should be a major consideration in the selection of the building location and layout on the CINT site, if the lowest possible vibration environment is required. It will thus be recommended that the most vibration sensitive functions be set as far from Eubank as possible. Other less sensitive building functions can be set closer to the road, of course.

These setback distances are conservative, as they are based on transient vibration and do not account fore any "building effect", which is the tendency for any building on the site to suppress the external vibration to some degree (as a function of frequency) due to its mass and stiffness. This is difficult to predict, however. In any case, it is highly probably that research requiring VC-E ambient vibration levels can effectively be located somewhat closer to the road than indicated above. The proposed 400 foot set-back distance for the CINT laboratories seems reasonable in this regard.

Figure 4: CINT Core Facility Site Vibration Study - 27 August 2002
Effect Of Vehicle Speed, Loaded Flat Bed at 160' (Location 8), Vertical, Maximum RMS

a) Narrowband (Bandwidth = 0.375 Hz)



b) One-Third Octave Band

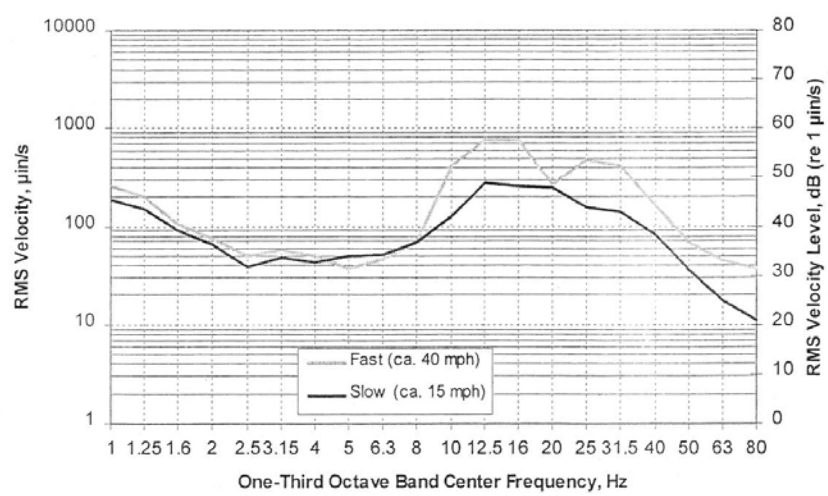


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Figure 5: CINT Core Facility Site Vibration Study - 27 August 2002
Maximum One-Third Octave Band Amplitude Versus Distance From Light Vehicles (Automobiles, Pick-ups, SUVs) on Eubank Boulevard, Maximum RMS, Vertical

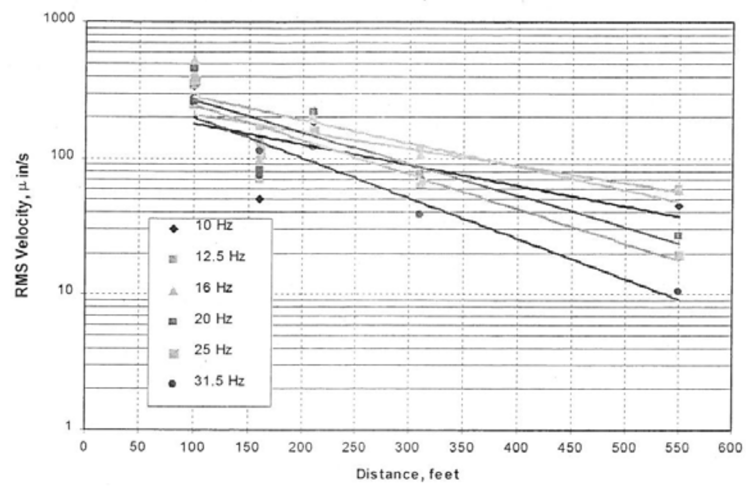
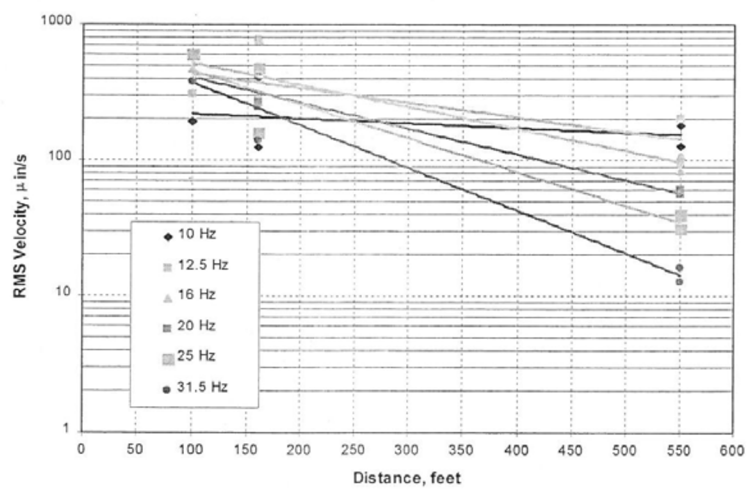


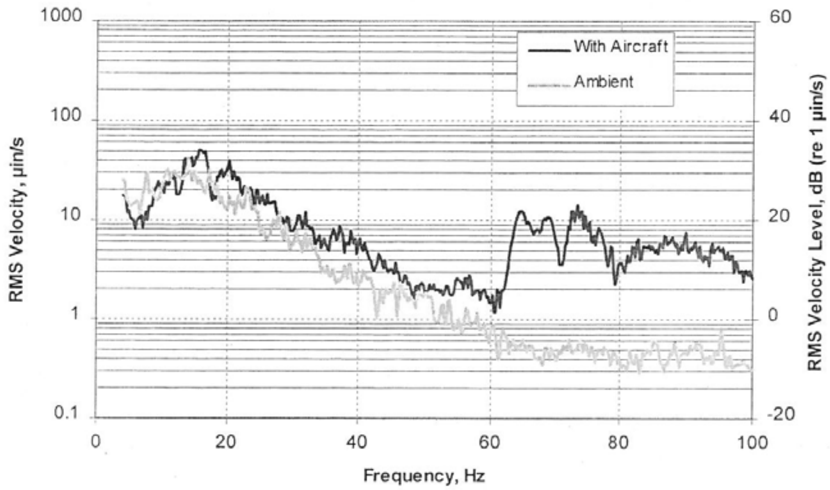
Figure 6: CINT Core Facility Site Vibration Study - 27 August 2002
Maximum One-Third Octave Band Amplitude Versus Distance From Heavy Vehicles (Flat Bed Trucks, Semis, Tank Trucks, etc.) on Eubank Boulevard, Maximum RMS, Vertical



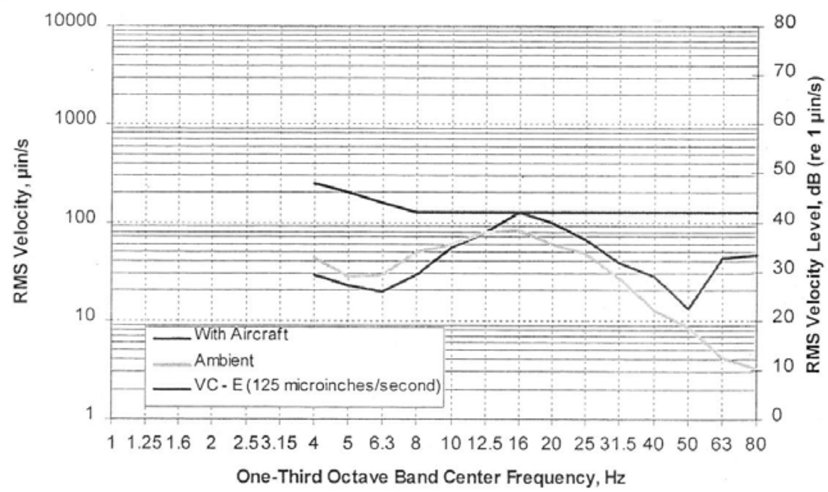
Aircraft vibration. As discussed in more detail below, various types of commercial and military aircraft fly quite low over the site due to the proximity of an airfield. During the vibration study, we occasionally measured ground vibration during aircraft overflights. Figure 7 shows the worst case example of our data from this type of measurement. These data were recorded when a twin engine propeller driven aircraft flew directly over the site. There is a significant increase in vibration above 60 Hz, and a smaller increase at other frequencies, resulting in an amplitude just reaching VC-E at 16 Hz. Other aircraft vibration impacts measured, such as from commercial jets (e.g., Boeing 757), were lower in amplitude.

Figure 7: CINT Core Facility Site Vibration Study - 27 August 2002
Location 1, Propeller Aircraft Flyover, Vertical, Linear Average RMS

a) Narrowband (Bandwidth = 0.375 Hz)



b) One-Third Octave Band



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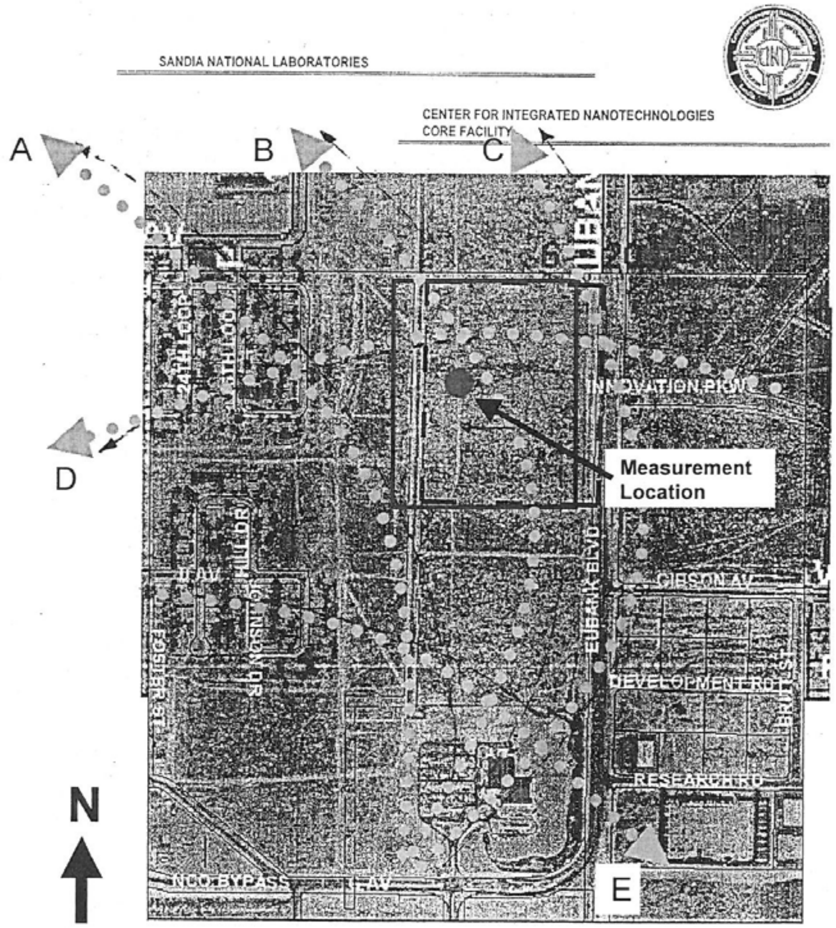
6. Presentation and Discussion of Aircraft Noise Data

Noise measurement location and flight paths. Figure 8 shows an aerial photograph of the proposed location of the Center for Integrated Nanotechnologies Core Facility. Noise from aircraft overflights was measured at the location shown in the figure, which had the best "line-of-sight" condition with respect to most of the aircraft flight patterns, and is distant enough from Eubank Boulevard to avoid significant traffic noise influence.

The aircraft often fly directly over the site, and at relatively low elevation, due to the proximity of the air field. These include commercial (smaller propeller type to large jets), military (fighter and transport), and small private aircraft of various sizes and propulsion type.

Figure 8: CINT Core Facility Site Noise Study – 10-11 September 2002
Plan of the Proposed CINT Core Facility Site, Showing Aircraft Measurement Location and Common Flight Patterns



HDR

Aircraft noise measurement data – continuous monitoring. Noise levels were monitored continuously during the measurement study. These measurement data are shown in Figure 9 in a plot of amplitude versus time. The A-weighted L_{eq} levels, along with the L_{10}, L_{50}, and L_{90} statistical centile levels, and other statistics, are shown in the plot. These data are averaged over 5 minute periods. The amplitudes vary dramatically due to the difference between the noise levels with and without aircraft. The L_{max} noise level peaks at 78 dBA; without aircraft the L_{max} is typically around 60 dBA due to ground traffic. The L_{eq} average varies between about 45 dBA and 60 dBA.

Aircraft noise measurement data – frequency spectra. Figures 10 and 11 show sample noise spectra measured on site while various types of aircraft passed nearby or overhead, measured using the L_{eq} and the L_{max} methodology, respectively. Figure 12 shows the highest noise levels measured from various aircraft in the five flight patterns shown in Figure 9. At times, the noise level due to aircraft reached 83 dBA (L_{max}).

Table 3 summarizes the data from our measurement study. The maximum octave band data gathered in the absence of strong winds (which tends to artificially increase the noise level in the 31.5 and 63 Hz bands) are included in the table.

Table 3: Summary of Upper-Bound Measurement Data of Ambient and Aircraft Noise

Case	Sound Pressure Level (dB re 20 μPa) versus Octave Band Center Frequency (Hz)								
	31.5	63	125	250	500	1k	2k	4k	8k
Maximum, Ambient	79	69	64	57	53	52	50	46	42
Maximum, Aircraft	89	85	84	83	81	78	72	61	41
Increase	9	16	21	26	29	26	22	15	0

Figure 9: CINT Core Facility Site Noise Study – 10-11 September 2002
Continuous Noise Monitoring Data, A-weighted Statistics over 5 Minute Periods

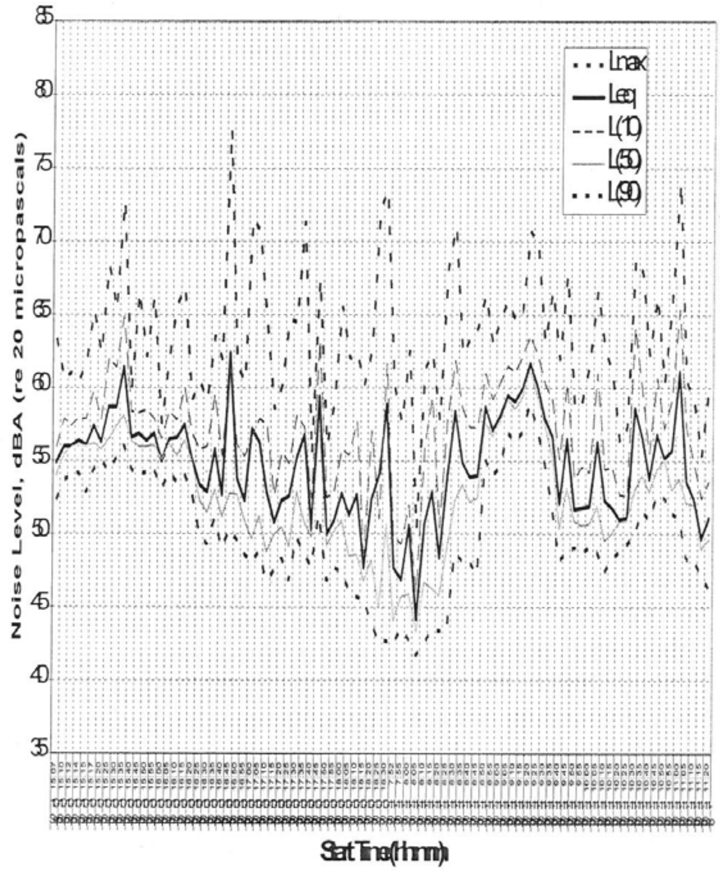


Figure 10: CINT Core Facility Site Noise Study – 10-11 September 2002
Aircraft Noise Spectra, L_{eq}

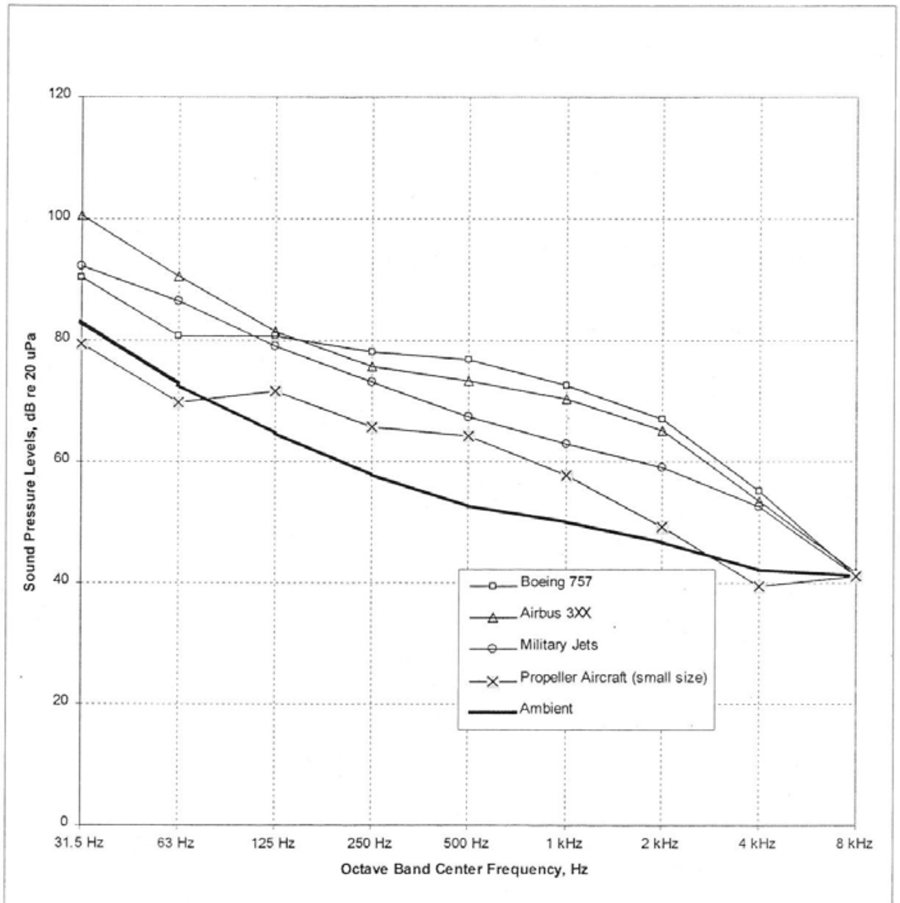


Figure 11: CINT Core Facility Site Noise Study – 10-11 September 2002
Aircraft Noise Spectra, L_{max}

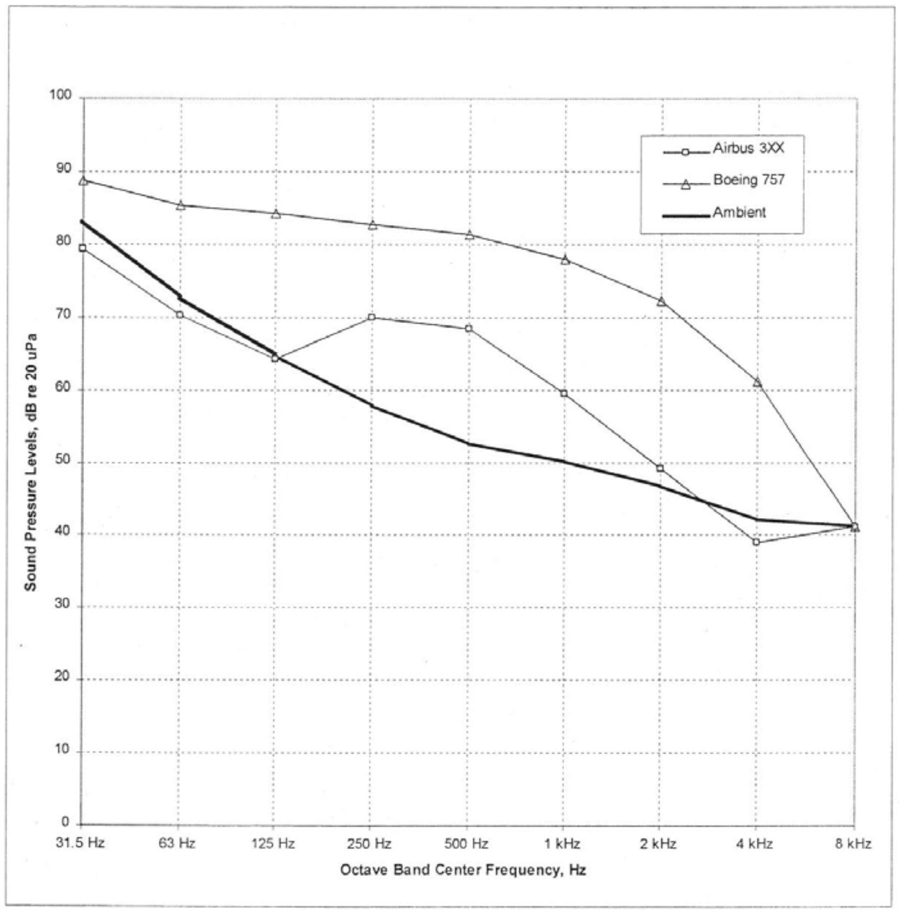


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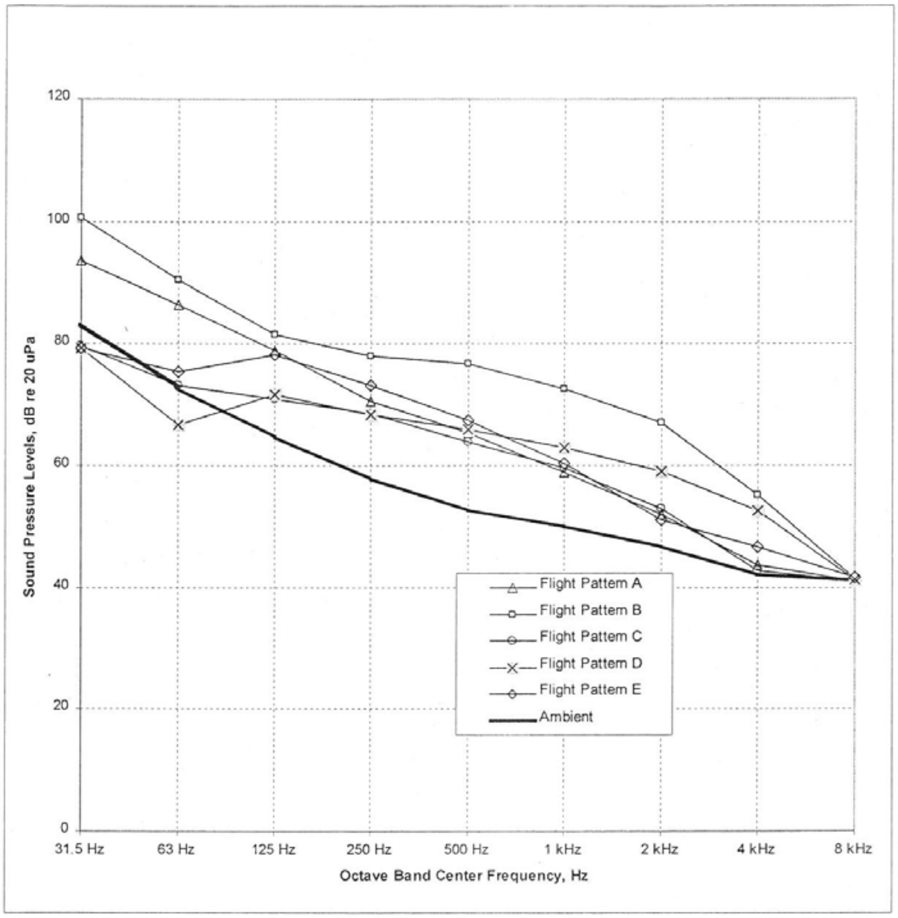
Figure 12: CINT Core Facility Site Noise Study – 10-11 September 2002
Maximum Aircraft Noise Spectra as a Function of Flight Pattern, L_{eq}



Building shell design implications. Impact to noise-critical rooms within the buildings (e.g., laboratories, private offices, conference rooms, teleconference rooms, etc.) can be controlled with care in the design of the building shell.

Several spaces within the proposed CINT Core building will be extremely noise-sensitive. The building shell will have to provide attenuation of aircraft noise. Table 4 summarizes the attenuation that will be required to meet several noise criteria (NC-25 being comparable to the requirements for a concert hall, NC-40 being appropriate for an office), using the upper-bound measurement data from Table 3 as input.[5]

Table 4: Building Shell Attenuation Required to Meet Several Noise Criteria (Based on Measured Maxima)

Attenuation Required to Meet:	Sound Transmission Loss (dB) versus Octave Band Center Frequency (Hz)							
	63	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
NC-25	31	40	46	50	51	48	39	20
NC-30	28	36	42	46	47	43	33	14
NC-35	25	32	38	41	42	38	28	9
NC-40	21	28	33	36	37	33	23	4
NC-45	18	24	29	32	32	28	18	-1

As the basis for comparison, Table 5 provides approximate transmission loss (in dB) for several common types of architectural construction.

Table 5: Sound Attenuation Characteristics of Several Common Constructions[6]

Construction Type	Sound Transmission Loss (dB) versus Octave Band Center Frequency (Hz)							
	63	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
4" Poured Concrete or Solid-Core Masonry	35	36	36	41	45	50	54	58
8" Poured Concrete or Solid-Core Masonry	36	37	41	45	49	53	57	61
6" Hollow-Core Dense Concrete Block or Masonry	33	36	36	38	44	48	52	56
6" "Cinder Block" or other Lightweight Porous Block Material	28	28	29	34	38	42	45	48
½" Glass Wall or Window	19	24	27	29	29	31	36	40

[5] It should be noted that the measurement data are the upper bound of the aircraft noise present on the days of our study. It is possible that noisier aircraft may occasionally fly over the site.
[6] These data are taken from Chapter 5 of "Noise Control for Buildings and Manufacturing Plants" by Laymon N. Miller

¼" Thick Double-Glass Window with 1-½" Air Space	19	26	30	34	38	37	41	46

It should be noted that the data given above are for single architectural elements, assuming adequate sealing. However, if the design involves a "shell-within-a-shell" approach, the desired noise reduction goals are attainable. The potential presence of unusually high low-frequency noise, however, will require unusually large air gaps between elements (e.g., between high-TL roof and high-TL ceiling), perhaps as a minimum on the order of 4-5 feet. This area can be used for piping and ducting, providing penetrations are adequately sealed and flanking is avoided.

¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤

This concludes our environmental vibration report on the proposed CINT Core Facility site near the Sandia National Laboratories campus. Please feel free to call if you have any questions regarding this report, or any other vibration and noise concerns.

APPENDIX III: NNSA / BES MEMORANDOM OF UNDERSTANDING

Department of Energy
National Nuclear Security Administration
Washington, DC 20585

JUL 1 6 2004

OFFICE OF THE ADMINISTRATOR

MEMORANDUM FOR: Dr. Raymond L. Orbach, Director, Office of Science, Department of Energy, HQ

FROM: Dr. Everet H. Beckner, Deputy Administrator for Defense Programs, NNSA

SUBJECT: Center for Integrated Nanotechnologies Project, SNL

The Center for Integrated Nanotechnologies (CINT) project is a Department of Energy (DOE) Office of Science (SC) sponsored Nanoscale Science Research Center that is jointly operated by Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL). The technical mission of CINT is to advance nanoscale science and technology and to provide physical capabilities to synthesize, examine, and integrate nanoscale materials and structures for the DOE and the international scientific community. The small dimensions of nanotechnology mandate that the experimental tools needed to advance this field require extremely quiet, low vibration, and stable conditions for normal operations.

The design of the CINT Core Facility that will be constructed by SNL and its physical location (on a 20 acre parcel within the approximately 87 acres of DOD land commonly referred to as the "Eubank Tract") has been developed to meet the most stringent criteria for vibration-sensitive equipment and processes (VC-E) defined under ISO 2631. The design has also addressed their electromagnetic sensitivities. These criteria are presented as Attachment A to this memorandum.

This office acknowledges that the performance baselines for CINT have been established via an SC Critical Decision 2 Energy Systems Acquisition Advisory Board, who's Acquisition Executive approved those baselines on August 20, 2003. I am committed to providing due consideration for the impacts that future Eubank Tract development would have on the CINT Core Facility operations. To bring this important programmatic issue to closure, I restate my previous assurance to the Office of Science that all future users of the Eubank Tract will comply with the requirements of Attachment A and that their operations will not adversely impact the CINT Core Facility.

Attachment

cc w/attachment:
P. Dehmer, SC-10, HQ
P. Wagner, SSO:

Attachment A

Center For Integrated Nanotechnologies Project

Vibrational and Electromagnetic Sensitivity Criteria

Scope of Work and Facilities Description

The Center for Integrated Nanotechnologies (CINT) is a DOE SC sponsored Nanoscale Science Research Center that is jointly operated by Sandia National Laboratories (SNL) and Los Alamos National Laboratory (LANL). The technical mission of CINT is to advance nanoscale science and technology for DOE missions and to provide physical capabilities to synthesize, examine, and integrate nanoscale materials and structures for the DOE and the international scientific community.

The CINT project was officially approved to occupy 20 acres, identified as Tract A-2, within the Eubank Tract by signed memorandum from the Albuquerque Operations Office Manager and dated March 11, 2002. This location of the CINT project was reaffirmed by memorandum signed by the National Nuclear Security Administration Administrator dated September 25, 2003.

The Core Facility is planned as a new office/lab facility to be located near Sandia's Tech Area I but outside the KAFB fence on Eubank Boulevard (near Research Park). The building will contain approximately 96,000 gross square feet (gsf), including 24,000 net square feet (nsf) of laboratory space. Included in this space are synthesis labs for chemical and biological work, characterization labs for optical and laser work, and Class 1000 clean rooms for integration operations. The building will also include classrooms, conference rooms, and interaction spaces to facilitate the exchange of information for multidisciplinary communication and development.

Unique design features of the building include: Class 1000 clean rooms with ability to achieve Class 1 with mini-environments, HVAC design for chemical free air streams, and structural and mechanical design to minimize vibrations in floor slabs.

Site improvements for this project include security fencing, service drives and yards, signage, parking, and landscaping. Site utility work will be extensive because of the distance that the existing Sandia utility infrastructure must be extended.

CINT Facility Functional Requirements

Mechanical Vibration

Because of the small dimensions of nanotechnology, (one nanometer is roughly the same as ten hydrogen atoms placed side-by-side) the experimental tools needed to advance this field require extremely quiet, low vibration, and stable conditions for normal operations. The design of the CINT Core Facility, that will be constructed by SNL, and its physical location have been developed to meet the most stringent criteria for vibration-sensitive equipment and processes (VC-E) defined under ISO

2631. Validation of the functional requirements for the CINT Core Facility (October, 2002) confirmed the need for the CINT Core Facility to provide laboratory space meeting the ISO VC-E criteria.

Prior to design of the CINT Core Facility, SNL contracted with Colin Gordon & Associates (CG) to examine the background vibration conditions on the Eubank site that was authorized by the DOE Albuquerque Operations Office Manager (March, 2002) for CINT use. The written report produced by CG (October 18, 2002) indicates that the authorized location for the CINT Core Facility can meet the VC-E requirement provided that the sensitive laboratory space within the CINT Core Facility has sufficient physical offset distance from existing and potential noise generating sources.

At the time of the CG report, vehicle traffic on Eubank Blvd. was the only existing source of ground vibration for the CINT Core Facility site. The CG study used detailed measurements of vehicular-generated ground vibration to arrive at the following recommendations.

- The CINT Core Facility sensitive laboratories must be separated by 550 ft. from heavy (truck) traffic.
- The CINT Core Facility sensitive laboratories must be separated by 250 ft from light (automobile) traffic.

The DOE SC approved CINT Core Facility design and location (Critical Decision – 2, August 20, 2003) provides the recommended physical separation distance from existing ground vibration sources.

Electro-Magnetic Interference

The operation of sensitive equipment within the CINT Core Facility such as the Electron Beam Writer and the Transmission Electron Microscope impose strict limits on the magnitude of stray electro-magnetic (E&M) fields that can be tolerated within the CINT Core Facility. The architectural design criteria used for the CINT Core Facility limits E&M fields to no greater than 1.0 milligauss (100 nanoTesla).

Impact on Eubank Tract Development

Infrastructure contributions

The CINT Core Facility Project has designed the utility infrastructure to facilitate development of the entire Eubank Tract where feasible. The following is a description of each utility and its capability to support development of the remaining lands to the north and south of the CINT Core Facility.

- Communications: A six-way duct bank is provided to the middle of the west side of the Core Facility lot with provisions for extension to the north. Telephone service will be available from the Core Facility communications room, but will require the purchase of the appropriate telephone switching equipment. Data service will require the installation of the appropriate fiber optic cable(s) through a spare conduit to the nearest main distribution room in SNL's Tech Area I.

- Electrical: A six-way duct bank is provided to the middle of the west side of the Core Facility lot with provisions for extension to the north. Two spare 5" conduits are available for development of the property north of the Core Facility. Electrical cables will be required to be installed to a manhole in SNL's Tech Area I to an available feeder.
- Water: Water can be connected to a 10" line at the northwest corner of the water line loop around the Core Facility. It is recommended that an additional connection be made to the north on the KAFB distribution system to provide a redundant source.
- Natural Gas: A 6" gas line is provided to the middle of the west side of the Core Facility lot with provisions for extension to the north.
- Sanitary Sewer: An 8" sewer line is provided to a manhole at the southwest corner of the Core Facility lot with provisions for extension to the north. It is anticipated that only the southern half of the north acreage can access this sewer line.
- Storm Sewer: The Core Facility acreage has no capability to accept any storm water flow from the lots to the north or to the south.

The proposed developer(s) shall be solely responsible for obtaining all necessary easements from the Kirtland Air Force Base (KAFB), including storm water runoff drainage easement, should they choose to connect to the existing KAFB infrastructure.

Synergy with Sandia Science & Technology Park

Nanotechnology is forecast to be one of the fastest growing sectors for business development with new product sales reaching $1 trillion by 2010 0 2015. The CINT mission to merge new nanoscience discoveries with technological development and to provide open access for the external scientific and technical community is ideally suited to complement the role of the Sandia Science & Technology Park (SS&TP) in attracting new business into New Mexico. CINT will act as an interface between new nanotechnology developed at the laboratories and commercial development of resulting business opportunities that can be pursued in SS&TP. By attracting the top university and industry scientists and technologiest to work with the best staff at the laboratories, they will be exposed to new business opportunities in New Mexico and the opportunities associated with new business development at the Sandia Science & Technology Park. Nanotechnology.

Vibration and Electro-Magnetic Field Generation Restrictions for Neighboring Developments

In accordance with the CG report, all future development of the Eubank Tract must meet the following restrictions to assure that CINT will continue to meet its functional requirements and mission needs.

- Future developers must not locate heavy vehicle traffic closer than 550 ft. from the CINT Core Facility sensitive laboratories.
- Future developers must not place light vehicular traffic closer than 250 ft from CINT Core Facility sensitive laboratories.

- Future developers must identify all construction or operating activities that have the potential to generate low frequency (less than 10 Hz) ground vibrations. If low frequency vibration sources are identified, the future developer must conduct vibration studies to measure the required offset distance needed to maintain VC-E criteria for CINT Core Facility sensitive laboratories. The future developer must also take appropriate steps to assure that low frequency ground vibrations associated with construction or operating activities will not interfere with CINT Core Facility VC-E vibration requirements. (The CG report noted that low frequency ground vibrations require longer distances to attenuate than do the 10 Hz to 30 Hz vibrations that are primarily associated with vehicular traffic. For this reason the future developers shall be responsible for assuring that their activities do not generate low frequency ground vibrations that could adversely impact CINT's ability to meet its functional requirements and mission needs).
- Future developers must identify all construction or operating activities that have the potential to generate electro-magnetic fields and demonstrate that such fields will not result in electro-magnetic fields within the CINT Core Facility that would exceed the building design limit of no greater than 1.0 milligauss in magnitude.

APPENDIX IV: AMEC FOSTER WHEELER PROJECT NO. 16-519-01563

December 14, 2016
Amec Foster Wheeler Project No. 16-519-01563

amec foster wheeler

Groundhog Construction Services
805 Nikanda Road NE
Albuquerque, New Mexico 87107

Attn: Troy Otero

Re: KAFB NACP Vibration Monitoring Report

In accordance with your request, the vibration monitoring of the above referenced construction project has been completed. Monitoring was performed from December 1st at 10:00 AM until December 5th at 1:21 PM, between the times of 7 AM and 7 PM. Vibration monitoring served to determine the intensity and frequency of vibrations experienced in the Sandia National Labs Center for Integrated Nanotechnologies (CINT) laboratory due to construction activities performed directly south of the building. The construction activities simulated the construction of a foundation in the lot adjacent to the CINT facility and included the following activities: vibration of the in place soil, excavation of a large trench, compaction of the bottom of the trench, and backfilling and compaction of the trench. Heavy construction equipment was used on site, and a time log of activities performed was provided to Amec Foster Wheeler. The construction site and associated facilities were monitored on December 1st and December 5th to establish a baseline for comparison of vibration activity in the absence of construction activity to vibration activity during construction.

Monitors used for this project were in the following areas: UM 10294 – Southwest CINT interior, UM 10834 – Southeast CINT interior, UM 10158 – Northeast CINT interior, UM 9152 – Western access road, UM 8396 – Eastern access road, UM 8697 – Adjacent to construction.
The results of vibration monitoring are summarized below:

<u>**Interior**</u>

- UM 10294 – Southwest CINT Interior
    - December 1, 2016 – peak vector sum of 0.005 in/s at a time of 13:57
    - December 2, 2016 – peak vector sum of 0.015 in/s at a time of 15:19
    - December 3, 2016 – peak vector sum of 0.012 in/s at a time of 07:38
    - December 5, 2016 – peak vector sum of 0.005 in/s at a time of 07:52
- UM 10834 – Southeast CINT Interior
    - December 1, 2016 – peak vector sum of 0.004 in/s at a time of 11:33
    - December 2, 2016 – peak vector sum of 0.011 in/s at a time of 15:02
    - December 3, 2016 – peak vector sum of 0.010 in/s at a time of 08:01
    - December 5, 2016 – peak vector sum of 0.005 in/s at a time of 07:52
- UM 10158 – Northeast CINT Interior
    - December 1, 2016 – peak vector sum of 0.004 in/s at a time of 10:05
    - December 2, 2016 – peak vector sum of 0.005 in/s at a time of 15:14
    - December 3, 2016 – peak vector sum of 0.005 in/s at a time of 10:51
    - December 5, 2016 – peak vector sum of 0.017 in/s at a time of 13:21

Amec Foster Wheeler Environment &
Infrastructure, Inc.
8519 Jefferson NE
Albuquerque, NM 87113
Tel (505) 821-1801
Fax (505) 821-7371

Access Road

- UM 8396 – Eastern Access Road
    - December 1, 2016 – peak vector sum of 0.007 in/s at a time of 18:00
    - December 2, 2016 – peak vector sum of 0.045 in/s at a time of 15:14
    - December 3, 2016 – peak vector sum of 0.028 in/s at a time of 07:56
    - December 5, 2016 – peak vector sum of 0.004 in/s at a time of 07:52
- UM 9152 – Western Access Road
    - December 1, 2016 – peak vector sum of 0.010 in/s at a time of 18:00
    - December 2, 2016 – peak vector sum of 0.036 in/s at a time of 08:32
    - December 3, 2016 – peak vector sum of 0.025 in/s at a time of 08:01
    - December 5, 2016 – peak vector sum of 0.004 in/s at a time of 07:52

Adjacent to Construction

- UM 8697 – Adjacent to Construction
    - December 1, 2016 – peak vector sum of 0.045 in/s at a time of 13:20
    - December 2, 2016 – peak vector sum of 0.083 in/s at a time of 11:23
    - December 3, 2016 – peak vector sum of 0.097 in/s at a time of 08:01
    - December 5, 2016 – peak vector sum of 0.038 in/s at a time of 10:18

Baseline vibration monitoring did not exceed 0.010 in/s in all locations except for the monitors adjacent to construction. The vibration of 0.010 in/s in the interior locations does exceed the tolerances for the equipment as transmitted to Amec Foster Wheeler by the end client. Higher amplitude vibrations were experienced adjacent to the excavation site. The location of the monitor and timing of the excitation indicates that the maximum vibration recorded on December 1 and December 5 may have been due to heavy vehicle traffic in the area, as the monitor was approximately 7-10 feet from the southern delivery route road. Construction activities were not performed on those days, which leads to the inference that heavy traffic was responsible for the excitation.

Construction vibrations did not exceed the OSBM or OSMRE specifications at any point during the construction at any vibration monitoring station. However, the tolerances of vibration transmitted to Amec Foster Wheeler for the transmission electron microscope and atomic precision fabrication were exceeded. Vibration monitoring summaries are included in Attachment A for your reference.

Thank you for this opportunity to work with you on this project. If you have any questions or concerns, please contact us at 1-505-821-1801 or by e-mail if you prefer.

Respectfully submitted,
Amec Foster Wheeler Environment & Infrastructure, Inc.

Lucas A. Giron, P.E.
Materials Engineer

Reviewed by,

Jacob S. Hays, P.E.
Materials Engineer

Attachments

APPENDIX V: WILCOXON RESEARCH MODEL 731A SEISMIC ACCELEROMETERS AND THE CRYSTAL INSTRUMENTS, SPIDER 80X BOX

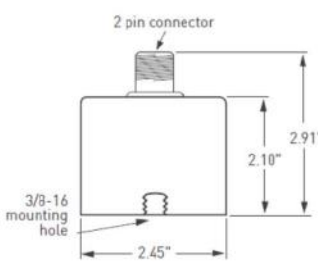
Seismic accelerometer and power amplifier

731A/P31 system

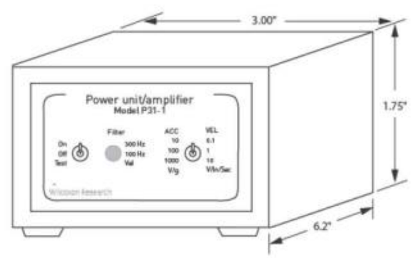
Wilcoxon
SENSING TECHNOLOGIES

Key features

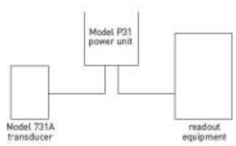
- Ultra high sensitivity
- Ultra low-noise electronics for clear signals at sub micro-g levels
- Low frequency capable
- Low pass filtered to eliminate high frequencies
- ESD protection
- Reverse wiring protection



Model 731A



Model P31



Powering with P31 power unit

Connections			
Output	**Connector**	**Function**	**Cable**
731A	shell	case	shield
	A	power/signal	white
	B	common	black
P31	shell	common	shield
	pin	signal	center conductor
Input	**Connector**	**Function**	**Cable**
P31	shell	ground	shield
	pin	power/signal	white
	socket	common	black

Note: Due to continuous process improvement, specifications are subject to change without notice.
This document is cleared for public release.

Wilcoxon Sensing Technologies
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Germantown, MD 20876
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Wilcoxon Sensing Technologies
An Amphenol Company

98079 Rev. C 08/17

Seismic accelerometer and power amplifier
731A/P31 system

Wilcoxon SENSING TECHNOLOGIES

SPECIFICATIONS

Acceleration sensitivity, selectable		10, 100, 1000 V/g	
Velocity sensitivity, selectable		0.1, 1, 10 V/in/sec	
Vibration range, max		0.5 g peak	
Amplitude nonlinearity		1%	
Frequency response:			
Filter	100 Hz	450 Hz	velocity
–10%	0.08 - 70 Hz	0.08 - 300 Hz	- - -
–3 dB	0.05 - 100 Hz	0.05 - 450 Hz	0.8 - 150 Hz
Transverse sensitivity, max		1% of axial	
Output impedance		2500 Ω	
Recommended load impedance		> 250 kΩ	
Maximum output voltage		5 V peak	
Noise:			
Spectral	**2 Hz**	0.03 μg/√Hz	
	10 Hz	0.01 μg/√Hz	
	100 Hz	0.004 μg/√Hz	
Grounding		case isolated	
Output connector:			
731A		2-pin, MIL-C-5015	
P31		BNC	
Input connector (P31)		twin axial BNC	
Power requirements (P31):			
Internal batteries		(2) 9-volt alkaline	
Battery life		> 75 hours	
Temperature range		–10 to +65° C	
Vibration limit		10 g peak	
Shock limit		fragile	
Base strain sensitivity		0.0001 g/μstrain	
Sensing element design		PZT ceramic / flexure	
Weight:			
731A seismic accelerometer		670 grams	
P31 power unit/amplifier		600 grams	
Interconnect cable, model 731A to model P31		R6-2T-J9-10	

Contact

Wilcoxon Sensing Technologies

20511 Seneca Meadows Parkway
Germantown MD 20876, USA

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Accessories supplied:

- Calibration data (level 3)
- SF7 mounting stud

Note: Special handling required due to sensitivity.

Note: Due to continuous process improvement, specifications are subject to change without notice.
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An Amphenol Company

CRYSTAL INSTRUMENTS

2370 Owen Street
Santa Clara, CA 95054, USA
www.crystalinstruments.com

Quote Number: 2017350M

May 18, 2017

Prepared For	Manufacturer Contact	Local Distributor
Victor Wowk Machine Dynamics, Inc. 1021 Commercial Drive SE Rio Rancho, NM 87124 www.machinedyn.com Phone: 505-898-2094	Ali Farrokhian Western Region Sales Manager Crystal Instruments 2370 Owen Street Santa Clara, CA 95054 Office: (408) 986-8880 Fax: (408) 834-7818 Mobile: (650) 714-9842 ali@sentekdynamics.com www.crystalinstruments.com	**Colin O'Connor** Sound and Vibration Specialists Sage Technologies Mobile: 480-296-9341 Office: 480-732-9848 coconnor@sagetechnologies.com www.sagetechnologies.com

Crystal Instruments is pleased to quote the following:

Part Number	Description	Delivery	Unit Price	Qty	Extended Price
S80X-P04	**Spider-80X Front-end: Four** 24 bit inputs (Voltage, IEPE), 102.4 kHz sampling, DSP, 4 GB data flash. BNC connectors. Includes Basic FFT Analysis Software (DSA-10-C08) **and** one output enabled (DSA-30).  **Note**: the product will be shipped with 8 input channels installed but with only 4 inputs enabled. The remaining four channels can be remotely enabled.	2 wk ARO	$8,500	1	$8,500
DSA-11-C08	**Octave Analysis and SLM Analysis** - Up to Eight Channels	2Wk ARO	$2,000	1	$2,000
DSA-20-C08	**Time Waveform Recording for Analyzer.** Record time streams up to sampling frequency of 102.4 kHz for all channels – Up to Eight Channels	2 wK ARO	$2,000	1	$2,000
EDM-01	PA Viewer: View data, export data to UFF, BUFF, MATLAB, user-defined ASCII, and wave files, Generate Professional Reports.	2 wK ARO	INC	1	INC
CI-T01	**One-Day Training at CI office in Santa Clara, CA.** Topic Include: • Basic Vibration Theory • Basic Signal Analysis Theory • Spider-80X Operation	2 Wk ARO	$1,500	1	$1,500
	Total				**$14,000**

APPENDIX VI: MACHINE DYNAMICS, INC. TEST REPORT

Machine Dynamics, Inc.
www.machinedyn.com

October 11, 2017

Mr. R Nick Davis, P.E.
Senior Project Manager
Structural Engineering
Bohannan Huston
7500 Jefferson St. NE
Albuquerque, NM 87109

Dear Mr. Davis:

This is a report of the vibration monitoring system installed at the CINT Facility, Building 518, Sandia National Laboratories. Approximately 20 days of background vibration activity has need accumulated. In addition, two tests were performed to judge the sensitivity of the facility to external construction activity:

A. An impact test of 1,500 Kg
B. A loaded dump truck

Six vibration spectrums are attached, along with photographs of test items and a satellite view of the facility.

Installed Vibration Monitoring System

A four channel vibration monitoring system has been installed. It consists of four Wilcoxon Research Model 731A seismic accelerometers, 10 V/g. They are placed on the floor, in a vertical orientation, in the following laboratory rooms:

Channel Number	Serial Number	Room Number
1	10554	1102B SPM Lab
2	10551	1522A Chase 1523 Optical Litho
3	10552	1112A Quantum Transport Lab
4	10553	1532 Flex Bay

The sensor signals are cabled, several hundred feet, to a dynamic signal analyzer in the control room. The analyzer is an 8-channel, Crystal Instruments, Spider 80x Box. Only channels 1 to 4 are active and populated. The analyzer averages data for 60-seconds from each sensor, then transfers the resulting auto-power spectrum to the host computer memory for storage.

1021 Commercial Dr. SE, Rio Rancho, NM 87124 • Mailing address: PO Box 66479,
Albuquerque, NM 87193-6479 www.machinedyn.com • info@machinedyn.com • (505) 884-9005

This data collection began the week of September 25th and runs continuously unless it is stopped. The vibration monitoring system was purchased by Sandia National Laboratory, is government property, and is intended to remain in place and operational indefinitely. Four additional cables have been placed above the ceiling to the four remote corners of the facility in anticipation of monitoring for external construction activity.

In addition, four power unit/amplifiers, Wilcoxon Model P31, with cables are available to relocate the accelerometers anywhere in the facility and view the signal data with any low- frequency portable dynamic-signal analyzer.

Activity Personnel

Machine Dynamics, Inc., provided a Senior Vibration Analyst, Victor Wowk, P.E., for calibration, interpreting and analyzing data, and providing technical assistance for the written report generation. Mr. Wowk is an off-site consultant.

The CINT Facility has designated a system administrator, Mr. Douglas Pete, to monitor and maintain the vibration monitoring system. He is an on-site Sandia National Laboratory employee.

Background Vibration Environment

The background vibration in the four laboratory rooms is shown in Plots-01, -03, -05, and -06. These are peak-hold averages, during a 20-second time period, and represent the typical statistical-peak levels that are not exceeded 98 percent of the time. The vibration criteria level of 3.0 micron/sec velocity (VC-E) is labeled on the plots. Three of the laboratory rooms remain below this limit, while Room 1112 exceeds it at 59.5 Hz. The source of this 59.5 Hz is a vacuum pump in the adjacent chase. This plotted data was captured by digitally recording the signals, then processing later via a separate FFT spectrum analyzer. This was done with peak-hold capture to characterize the worst conditions during background monitoring and during the dump truck test.

The permanently installed vibration monitoring system is accumulating data with exponential averaging. This suppresses the transient peaks, but does characterize the broadband steady-state levels. In that mode, all laboratory floors monitored remain below the 3.0 micron/sec level, even Room 1112.

The generic VC criteria is specified to be acquired in 1/3 octave bands rather than narrow band frequency spectrums. Narrow band frequency spectrums are being captured to facilitate diagnosis and analysis of specific sources. It should be recognized that 1/3 octave bands will accumulate data over a wider bandwidth and will, therefore, report a higher amplitude within the 1/3 octaves.

The generic criteria also allows data to be acquired over a time length of 20 second to 2 minutes in linear averaging or peak hold averaging. Linear averaging is preferred for steady state background data, while peak hold averaging is recommended when transients are present. Exponential averaging emphasizes the most recent data with more weighting and de-emphasizes older data. For steady state background vibrations, linear and exponential averaging should be comparable, where peak hold averaging will be higher depending on the severity of transients.

Impact Test

A portable hardness tester was used to generate a 1,500 Kg impact onto a steel plate. A photograph of the typical test setup is attached. This testing was done outside the northeast corner of the facility. The closest sensor in Room 1102, SPM Lab, was observed while the hardness tester impacted the steel plate several times.

With the steel plate on dirt, no discernible shock pulse was visible above the normal background environment. With the steel plate on the concrete walk outside the northeast door, shock pulses were visible in the time waveform at levels approximately three times the normal background.

The conclusion from this impact testing is that the dirt around the CINT Facility provides a good isolation barrier to impacts that create high-frequency vibration.

Dump Truck Test

A fully loaded dump truck was commissioned to drive around the south side of the facility. A photograph of the actual truck used is attached along with an aerial view of its travel route. On the south side access road, one half of the tires were on the pavement, while the other half traveled on the uneven dirt adjacent to the pavement. The truck was loaded with 23 tons of rock and dirt for a total weight of 80,500 pounds. The dump truck traveled the route three times during which data from the four seismic accelerometers was digitally recorded with a Teac RD-101T PCM DAT Recorder. The data was later replayed into an FFT analyzer. The most active signals, when the dump truck was rolling close to the building, were captured in a peak-hold averaging mode. The results from the two nearest seismic accelerometers are shown in Plots 02 and 04. The truck activity creates a significant low-frequency motion at 3.0 Hz plus broadband activity between 10 to 30 Hz. In the peak-hold averaging mode, these vibrations exceed the 3.0 microns/sec limit. In the exponential-averaging mode from the Crystal Instruments box, the same vibrations are visible but the levels remain well below 3.0 microns/sec.

The 3.0 Hz vibration, being of very low frequency, is the one likely to be troublesome, if at all. The physical source of this is something very large and resonant, being energized by the broadband random energy of the dump truck motion. It could possibly be the roof. This 3.0 Hz vibration was visible at all four sensor locations, even those on the north side. The north side sensors did not display any significant vibrations in the 10- to 30-Hz range during the truck motion. The spectral pattern from the north side sensors was very similar to normal background motion with a very small peak at 3.0 Hz.

Conclusions

1. The normal background vibration environment at the CINT Laboratories remains below 3.0 microns/sec, with the exception of Room 1112 Quantum Transport Lab.

2. High-Frequency impact motion from construction activity is not likely to affect the facility.

3. Heavy truck movement, moving dirt around, compacting, pile driving, etc., will likely cause low-frequency motion activity below 30-Hz detectable by the nearest sensors. The transient amplitudes will remain near the VC-E limit of 3.0 microns/sec.

Respectfully submitted,

Victor Wowk

Victor Wowk, P.E.

Enclosures: Six plots, Photograph of Impact Testing, Photograph of Truck, Map of Truck Route.


RIEHLE TESTING

Bohannan Huston – Sandia National Laboratories
CINT Facility – Path of Loaded 80,500 Dump
Truck October 7, 2017

The dump truck traveled the red path three times.

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DISTRIBUTION

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Assistant Manager for Engineering
Sandia Field Office
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